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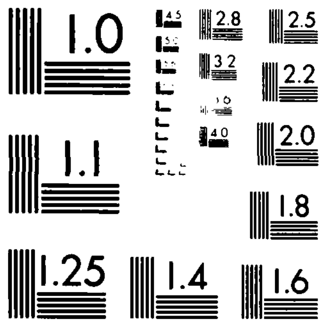

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AD-A149 493

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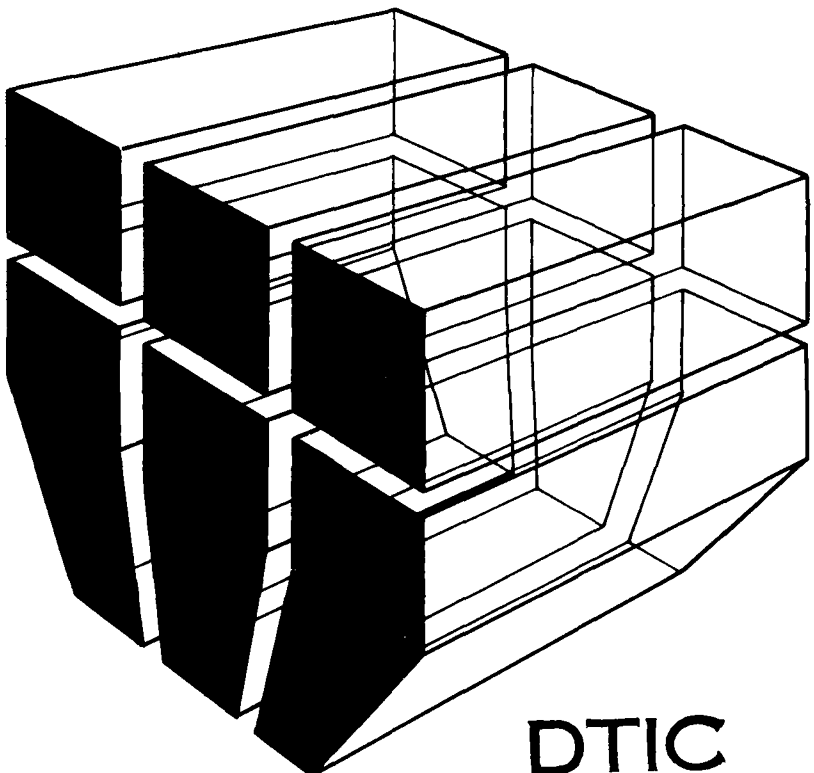

by
B. J. Sliwinski

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Results are presented for an energy analysis of the Corps of Engineers (CE) dredge plant. The purpose of the study was to establish suitable baseline measures of dredge energy consumption that could be used in the Army's program for energy management goal development. ~~As a~~ first, ~~step,~~ energy and operations data were collected and analyzed for hopper and nonhopper dredges comprising the Corps of Engin~~eers~~ Minimum Dredge Fleet.

BLOCK 20. (Continued)

Based on this analysis, the baseline measure recommended for use in goal setting and monitoring is the amount of energy consumed per hour of dredge operation, expressed in MBtu/hr. MBtu/hr is considered to be the measure most responsive to changes in operation and the most sensitive to variations in gross energy consumption. It is also recognized, however, that MBtu/thousand cu yd of dredged material may be a useful measure in some project-specific situations. Recommendations are made with respect to areas in which current dredge energy and operations data collection could be modified to improve the Corps' ability to monitor ~~dredge~~ energy consumption.

Technical- and management-based energy conservation opportunities are described, ~~These are~~ evaluated for applicability to the Corps dredge plant and for maximum potential energy savings. The individual strategies are applied on a dredge-specific basis to establish an upper limit for conservation levels expected from each dredge. Since not all of the conservation opportunities can be expected to pass detailed engineering/economic criteria for each dredge, the maximum potential energy conservation levels may be considerably higher than the final goal levels established by the Corps. Finally, several tentative goals are proposed for the Corps dredge energy management program.

FOREWORD

This report was prepared by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) Energy Systems Division (ES) based on a study by the University of Michigan College of Architecture and Urban Planning. The study was a reimbursable effort for the Directorate of Civil Works, Office of the Chief of Engineers (OCE), under IAO CWO-M-82-16 dated May 1982. The OCE Technical Monitor was James Bickley, DAEN-CWO-M.

Contributing to the University of Michigan study were Mark R. Berg, Mark L. Hassett, Matthew F. Rose, and Mitchell J. Rycus. Dr. Allen G. Feldt contributed to the research design and early stages of this research. As part of an earlier contract, Jerry Mitchell prepared an analysis of environmental and other regulatory constraints to dredging which provided background for this study. Gerald Greener, John Magyarik, Keith Lawrence, and John Bouldin are acknowledged for suggestions on the preliminary versions of this report. Thanks also go to Jackie Bourn, Elaine Cooper, Anderson Keen, Jerry Ptak, Bob Sanders, Henry Schorr, and J. V. Teague for help during the field visits and data acquisition in the University of Michigan study.

R. G. Donaghy is Chief, USA-CERL-ES. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The Civil Works Program of the U.S. Army Corps of Engineers (USACE) is responsible for water resource management at the national level. Civil Works responsibilities include navigation, flood control, hydroelectric power, water supply, recreation, and fish and wildlife conservation. The cost of energy consumed by Civil Works programs has increased greatly in the past several years; these programs consume approximately 8,000,000 MBtu per year at a cost of $40 million. Petroleum products account for much of the energy consumed. Engineer Regulation 11-1-10[1] directs the Corps to reduce its petroleum energy consumption. Major consumers of petroleum fuels within USACE are process operations such as dredging, mat laying, operating locks and dams, and pumping. Previous work has identified preliminary baseline efficiency indicators for these processes,[2] and has shown dredging to be the major process energy consumer--and thus the largest petroleum energy consumer in the Corps.

The Corps dredging mission has undergone major change in the past 5 years and, as a result of Public Law (PL) 95-269, the way in which ports, harbors, and waterways are maintained has changed dramatically. The law's greatest impact has resulted from the mandated reliance on contractor-run dredges for most national dredging needs. Thus, a function once done entirely by a Corps-owned and -operated dredge fleet now depends heavily on contract labor. As a result, most of the older Corps plant has been retired and three new Hopper dredges have been constructed.

The private dredging industry has responded to the increased availability of work by constructing many new dredges, both hopper and nonhopper. However, the private fleet differs from the Corps-owned fleet in several important ways. The Corps plant has been engineered heavily to accommodate the military support function the plant must provide in time of national emergency. These additional design criteria have produced a plant substantially stronger, more seaworthy, and more mechanically redundant than that typical of private industry. This has implications for the Corps fleet's energy consumption, since a larger, heavier plant is likely to consume greater amounts of fuel.

To conserve energy in dredging, energy conservation goals must be developed. An earlier study gathered energy consumption and productivity data for

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[1]Engineer Regulation (ER) 11-1-10, Corps of Engineers Energy Program (U.S. Department of the Army, 15 April 1982).

[2]B. J. Sliwinski, Determination of Civil Works Energy Consumption Baselines, Technical Report E-182/ADA127871 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1983).

Corps dredging operations and completed a preliminary goal development analysis.[3] To define specific energy conservation goals for USACE dredging, guidance is needed on which strategies would best suit Corps needs.

Objectives

The objectives of this study were to: (1) complete data gathering and analysis to determine the best baseline efficiency indicator for dredging; (2) evaluate energy conservation technologies and management strategies that apply to dredging operations; and (3) develop conservation goals based on these technologies in terms of the baseline efficiency indicator.

Approach

A complete set of consumption and process level data was gathered from existing USACE reporting systems. This included information from the Defense Energy Information System (DEIS) and from consolidated Reports of Operations for Hopper Dredges (ENG Form 27). The St. Louis, Detroit, Vicksburg, and New Orleans USACE Districts were visited to obtain field data. All data gathered were subjected to a detailed statistical analysis to determine the best form of a process energy efficiency indicator for dredging operations. The three indicators judged most promising for this task were MBtu/hr, MBtu/Ehr (where Ehr = effective hours), and MBtu/cu yd.

Energy conservation technologies that apply to dredging operations were evaluated through (1) an extensive review of the dredging technology literature, (2) contacts with suppliers to the dredging industry, and (3) discussions with experts at the USACE Water Resources Support Center and Marine Design Center. A literature review was conducted to find management strategies that potentially apply to Corps dredging.

Energy conservation goals were developed by assessing the energy conservation potential of the applicable technologies and stating this potential in the form of the chosen process energy efficiency indicator.

Management-based strategies were reviewed from the limited literature on this subject. Some strategies were suggested as supplemental to the energy management program.

Techniques for goal development were researched and suggested as guidelines for Corps use in deciding energy conservation goals.

Scope

This study was limited to the USACE dredge fleet. Energy requirements for the contractor fleet were not considered.

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[3] M. J. Rycus, M. L. Hassett, M. R. Berg, M. F. Rose, J. V. Mitchell, and A. G. Feldt, Civil Works Energy Goals for Dredging and Lock and Dam Operation: Evaluation of Data Base and Mission-Related Constraints, Unpublished Technical Report E-198 (USA-CERL, July 1984).

Mode of Technology Transfer

It is recommended that the results of this study be incorporated in the annual update of ER 11-1-10.

Table 1 shows how the split of dredging yardage between the Corps and contractor plant has shifted. Starting with the Industry Capability Program (ICP) in the late 1970s and culminating with the Minimum Fleet regulations under PL 95-269, there has been a progressive lessening of the Corps' role in the dredging program.

At present, the minimum fleet required to support the dredging mission in times of national emergency consists of four hopper dredges and six nonhopper dredges. Cutterhead and dustpan dredges make up the core of the nonhopper fleet and are used mainly to maintain the Inland Waterway System. Table 2 shows the minimum fleet's current configuration. Sidecasters and the special-purpose dredge Currituck were excluded from this analysis since thei[illegible] [illegible]tion is estimated to account for less than 5 percent of the energy [illegible].

Data Collection

For an accurate analysis of energy use by the Corps dredge fleet it was necessary to collect comparable data sets for all dredge types (hopper, dustpan, and cutterhead). Most data used in this analysis were obtained from the dredge reporting forms--Engineering Form 27 for the hopper dredges, and Form 4267 for the dustpan and cutterhead, except for the cutterhead Thompson which reported on Form NCS 340. Fuel data for the Thompson came from Form NCS 730 and those for the Potter and Ste. Genevieve were from Form 4A. These forms, when completed correctly, document both operational and energy consumption profiles for the dredges. Districts were asked to send a set of reporting forms representative of a dredging season. Some issues noted during this process resulted in inconsistencies that make it difficult to collect accurate data. These included the districts' use of different forms for reporting, separation of operations and fuel consumption data, and lack of data for newer dredges.

Form Consistency

Most Corps districts use either Form 27 or 4267, but some use different reporting forms. In addition, some districts fill out only daily forms or create their own summary forms. The use of different forms made it necessary to aggregate and reorganize the data to form a common data set for all dredges.

Another consistency issue was the reporting frequency. Some districts fill the forms out for each project whereas others complete them on a monthly or daily basis. This variability was seen as a potential problem in analysis since there is no consistent reporting timeframe.

Energy Reporting

The data analysis requires fuel consumption data to be matched with dredge operations data over the same time period. Although some districts report energy consumption along with the operations data on Form 27 or 4267, others use separate energy reporting forms, such as materials and supplies monthly receipt forms. This separation makes it difficult to align operations data with fuels use.

Table 1

Change in Use of Corps- Versus Contractor-Owned Plant*
(Million Cubic Yards)

	1977	1978	1979	1980	1981	1982
Contractor Plant	169.6	186.1	191.3	214.8	271.2	212.5
Government Plant	128	94.1	89.2	81.7	87.6	59.6
TOTALS	297.6	280.2	280.5	296.5	358.8	272.1

*Data are from the Water Resources Support Center (WRSC-D), Fort Belvoir, VA.

Table 2

Corps Minimum Fleet: Current Configuration

Dredge	Dredge Type	Size	District
Wheeler	Hopper	8400 cu yd	New Orleans
McFarland	Hopper	3140 cu yd	Philadelphia
Markham*	Hopper	2680 cu yd	Buffalo
Essayons	Hopper	6000 cu yd	Portland
Yaquina	Hopper	825 cu yd	Portland
Thompson	Cutterhead	20 in.**	St. Paul
Ste. Genevieve	Cutterhead	20 in.	St. Louis
Jadwin	Dustpan	32 in.	Vicksburg
Potter	Dustpan	32 in.	Memphis

*At the time of this study, there was still some question about the dredge Markham's status. This table does not show the sidecasters or special-purpose dredges.
**Pipeline diameter.

Age of the Hopper Fleet

Another major issue affecting data collection was the availability of hopper records. Most of the Corps hopper fleet is newly constructed and has been in operation for a limited time. Therefore, project reports were limited for some of the dredges and, in the Essayons' case (Portland District), the dredge is still in its trial period and data are unavailable. Operations and fuel consumption data for the Yaquina (Portland District) and the Wheeler (New Orleans District) were limited since both vessels have only recently ended their trial periods.

Field Visits

In addition to collecting data from dredge reporting forms, the various districts were visited to meet with Corps personnel who operate the dredges. These field trips included visits to selected dredges and permitted a first-hand view of dredge operations. Field work was valuable in this study since the dredge operators have a unique understanding of their dredges' performance. The following districts were included in the field visits.

St. Louis District

Discussions were held with the Chief of Plant and Dredging Branch. The Corps dredge mission for the Upper Mississippi River was emphasized and data were secured for the cutterhead dredge Ste. Genevieve and the dustpan dredge Potter. Arrangements were made to visit the cutterhead dredge Thompson at Hannibal, MO.

Detroit District

The Detroit District office was visited several times for discussions with the district energy officer and for use of the district library. Arrangements were made to visit the hopper dredge Markham at Saginaw Bay, MI.

Vicksburg District

Dustpan dredges were discussed with Corps personnel, giving special attention to engine repowering. The dustpan dredge Jadwin was visited and some data were secured. Also, the U.S. Army Waterways Experiment Station (WES) was visited to gather additional information on dredging.

New Orleans District

Since the New Orleans District manages two-thirds of all Corps and contract dredging, personnel were interviewed about agitation dredging and the increasing role of private dredge contractors.

Data collected during these visits along with those from the dredge reports formed the basis for a statistical analysis.

Statistical Analysis

The purpose of this analysis was to establish an appropriate baseline measure to use in defining energy consumption and conservation goals. A suitable baseline measure is one that has energy consumption as the dependent variable and some other variable (or set of variables) that best relates to energy consumption as the independent variable(s), taking into account the following criteria:

- The measure should be based as much as possible on data, or reassembly of data acquired in the dredging operation
- The measure should be statistically consistent in that values for it are reproducible within explainable variances
- Values of the measure should reflect changes attributable to both mission changes and changes in operational efficiency.

The first criterion required that common data sets be gathered for all dredge types (hopper, cutterhead, and dustpan) over a common time period as described previously. The data were then transferred to files for statistical analyses using the University of Michigan's Interactive Data Analysis System (MIDAS).

The following operational variables were taken from the dredge reporting forms:

- Energy consumption in barrels or gallons
- Measures of effective and ineffective time
- Amount dredged
- Total number of loads or amount advanced
- Measures of dump time
- Discharge pipe length.

In addition, site variables such as reporting period and in-place density or voids ratio were also identified for the analyses.

Since a suitable measure requires energy consumption to be the dependent variable, million British thermal units (MBtu) was chosen because it is already well established in USACE reporting procedures. Furthermore, it is easily derived from other forms by simply converting barrels or gallons to an equivalent Btu value.

The other variable (or set of variables) would need to come from some measures of productivity such as time spent or material dredged. Accordingly, new variables were generated that consist of ratios of energy consumption to the various measures of time and material dredged. These ratios were used to establish measures of energy consumption per unit of productivity that could be compared within dredge types.

The second criterion requires that the measure be statistically consistent. This means that values for the measure should be reproducible over some reasonable time period, and that large variations from some established baseline value can be reasonably explained. This would involve first determining average values for the measures, their ranges, variances, and other descriptive measures of central tendency and dispersion. A next step would be to select measures that either exhibit the least variance or for which the sources of variances can be explained. Analysis of variance (ANOVA) and correlation analyses were conducted to aid in this selection.

The third criterion requires that values of the measure be sensitive to mission changes and to operational efficiency changes. This also requires an understanding of the variance sources.

Establishing a Suitable Measure

To establish a suitable measure as defined above, a descriptive statistical analysis was performed to generate the maximum, minimum, mean, and standard deviation for each variable. The results showed that the most uniform and least ambiguous data were obtained for project or monthly summaries as opposed to daily or other partial reporting periods. Furthermore, since only project or monthly summary data were available for some dredges, this type data was used in all analyses. This allowed for comparisons across all dredges over common reporting periods.

Of the various energy consumption ratios, three had the most potential as candidate measures:

1. Energy consumed per total operational time* (MBtu/hr)

2. Energy consumed per total effective time (MBtu/Ehr)

3. Energy consumed per thousand cubic yards (MBtu/Kcu-yd).

Findings From Descriptive Statistics

Appendix A contains descriptive statistics for each dredge. These data indicate that the range of values between dredges for the three potential measures is highest for MBtu/Ehr (83) and smallest for MBtu/Kcu-yd (39) (Table 3). However, range alone is not necessarily a valid criterion for selecting a baseline measure, since it is not expected that any one value of a measure will be selected for all dredge types or even for all dredges within each type. A more important criterion is the variance in each measure for each dredge type.

*In this report, "total operational time" means the sum of the total effective time and the total noneffective time minus the lay time.

Table 3 summarizes these data for the three most promising baseline measures. Figure 1 is a plot of MBtu/hr and MBtu/Kcu-yd from this data set with the average bounded by one standard deviation.

Table 3 lists the dredges in order of size within each dredge type. Several trends can be observed from this arrangement. First, MBtu/hr is related positively to dredge capacity (or size) for the hopper and dustpan dredges (Table 1). Furthermore, the standard deviations, and therefore the variances, are generally smaller for MBtu/hr than for either MBtu/Ehr or MBtu/Kcu-yd. This is important, since a smaller variance for a specific dredge on any given job implies a reduced likelihood of obtaining values far from the mean. Thus, MBtu/hr may be the best measure for the hopper and cutterhead dredges because the second selection criterion requires that variances be either small or reasonably explained. It should be noted that measures with large variances, even in cases for which the sources of variance have been identified, are less likely to result in consistent values across different jobs. This makes them more cumbersome to use when trying to monitor goal achievement. For dustpan dredges, the variances are about the same for both MBtu/hr and MBtu/Kcu-yd. Therefore, under the minimum variance criterion, either measure may be suitable.

Findings for Analysis of Variance (ANOVA)

To better understand the sources of variance, an ANOVA was conducted to test the hypothesis that, for each of the three potential measures, the averages and variances within each dredge type were statistically the same. If this were true, then it could be reasonably assumed that the major sources of variance for that dredge type (i.e., time-based or production-based variables) are the same because they have the same underlying distribution. Furthermore, if the underlying distribution were the same, statements could then be made about the averages of the measures--for example, whether they are the same for each dredge type. If the averages of the measure were the same, a single goal for that dredge type could be considered.

Table 4 summarizes results of the analysis. Appendix A contains the complete results.

The 0.05 level of significance has been used throughout the statistical analysis. This means that the probability of rejecting a true hypothesis is 5 percent, which is seen as a reasonable level of significance for such small data sets. However, the less conservative level, 0.1, is also shown in cases for which the results change. These cases also should be considered to reach reasonable conclusions.

Table 4 shows that, for the hopper dredges (and cutterhead dredges at the 0.1 level), there is no evidence to accept the hypothesis of equal variances for the time-related measures. In the case of dustpan dredges, there is no evidence to reject the hypothesis of equal variances for all three measures. Note also that the variances for the MBtu/Kcu-yd for hoppers and cutterheads are the same statistically. In cases for which equality of variances are accepted, the underlying distributions are assumed to be the same. This implies that if equality of means are also accepted, then a single value for that measure can be used for that dredge type. Equality of variances and means were accepted for the MBtu/Kcu-yd measure with both hopper and dustpan dredges.

Table 3

Range of Values for Candidate Energy Consumption Measures

Dredge	Type	N	MBtu/Ehr	SD	MBtu/hr	SD	MBtu/Kcu-yd	SD
Wheeler	H	2	95	26	53	19	32	4
McFarland	H	10	38	13	29	10	56	32
Markham	H	18	22	2	18	3	56	38
Yaquina	H	10	21	7	13	3	38	22
Thompson	C	6	19	7	7	2	17	8
Ste. Genevieve	C	4	57	19	33	4	55	19
Jadwin	D	5	101	13	59	5	30	4
Potter	D	4	62	10	40	6	31	4
Range (Max. - Min.)			83		52		39	

Note: H = hopper, C = cutterhead, D = dustpan,
N = number of data points, SD = standard deviation.

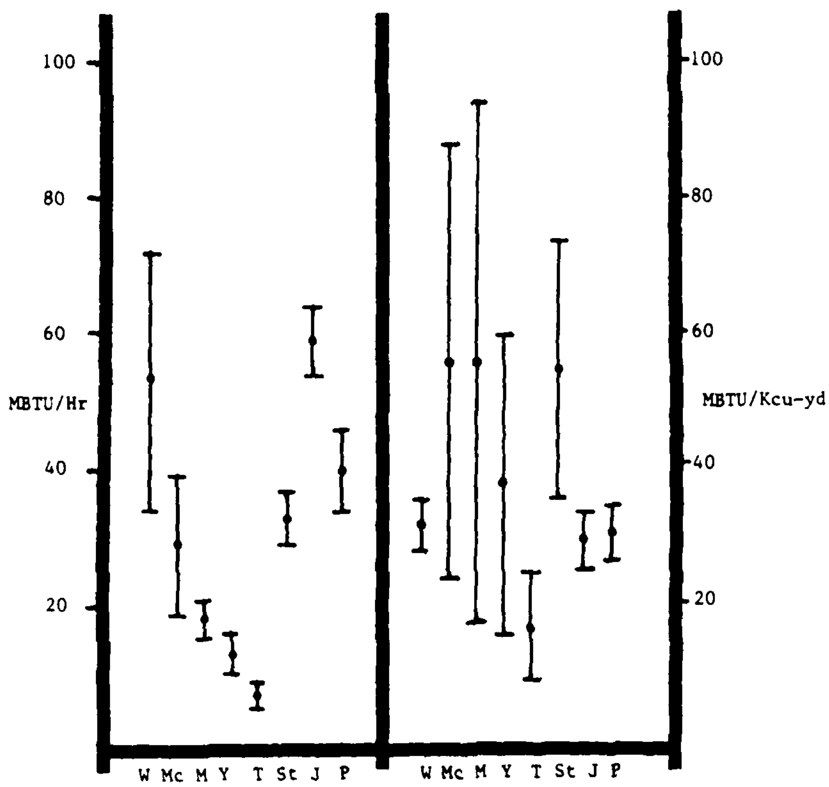

Figure 1. Plot of values for candidate energy consumption measures.

Table 4

Results of ANOVA for MBtu/Ehr, MBtu/hr, and MBtu/Kcu-yd Variables

	Hopper			Cutterhead			Dustpan		
Measure*	1	2	3	1	2	3	1	2	3
Equality of variances**	R	R	A	A***	A***	A	A	A	A
Equality of means	R	R	A	R	R	R	R	R	A

*Measures: 1 = MBtu/Ehr, 2 = MBtu/hr, 3 = MBtu/Kcu-yd
**R = reject, A = accept the hypothesis at alpha = 0.05.
***Reject at the alpha = 0.1 level.

Equality of variance by itself has some implications. Acceptance of the same underlying distribution can mean that the dredges operate under similar conditions and, as a result, if the sources of variance can be identified for one dredge, then the same sources can affect the other dredge. If MBtu/hr were chosen as a suitable measure because of the least variance criterion, the effect of mission or efficiency changes on the MBtu/hr values should be easier to isolate for dustpans. Since this factor relates to the third criterion, MBtu/hr may be a suitable measure for the dustpans; it could also be appropriate for the hoppers and the dustpans if the sources of variance for each individual dredge could be identified. On the other hand, MBtu/Kcu-yd could be a suitable measure for hoppers and cutterheads if the sources related to the very large variances in this measure could be explained with some degree of certainty.

Table 4 indicates that the only instance for which both equality of variances and equality of means are accepted is the MBtu/Kcu-yd measure for hoppers and dustpans. Figure 1 shows the reason for that result in the hoppers' case: the large variances of this measure have considerable overlap and, as a result, almost any values for the mean found in the overlapping variances would be statistically accepted as equal. For the dustpans, however, the equality of both variances and means is truly demonstrated. As for the other cases, rejecting equality of means simply implies that each dredge has its own operating characteristics.

It appears that the MBtu/hr measure is suitable for the dustpans and could be appropriate for hoppers and cutterheads if the variance sources for each dredge could be identified. The MBtu/Kcu-yd measure also could be a suitable measure for the dustpans, but would only be appropriate for hoppers if sources for the large variances could be identified clearly. The MBtu/Ehr measure does not appear to offer any advantage over MBtu/hr since MBtu/Ehr has a larger range and shows greater variance. The next task was to identify variance sources in the measures.

Identifying Sources of Variance

Two analyses were conducted to identify the sources of variance: stepwise regression and correlation. Stepwise regression was chosen because it can be used to determine the relationship between energy consumption and the other variables; it can also be used as a predictive model. In cases for which too little data were available to use the regression model, bivariate correlation analysis was used to establish the strength of the relationship between the dependent variable (energy consumption) and one independent variable at a time.

Regression Analysis

A stepwise regression analysis using standardized variables was conducted for dredges with enough cases for analysis. The dependent variable was total energy consumption in MBtu. Since the analysis was limited to monthly or project data, only three of the four hopper dredges and none of the cutterheads or dustpans had enough data to perform the analysis. This was somewhat disappointing since it is for hopper and cutterhead dredges that individual explanations for variance sources are most needed. Appendix A contains the output for this analysis, and Table 5 summarizes findings for the three hopper dredges.

Table 5 shows that the effective time components for the Markham and Yaquina are the most prevalent independent variables and are responsible for explaining most of the variance, as the high R^2 values imply. These high R^2 values also allow beta weights to be used with significant confidence in a predictive model to estimate future energy consumption. Beta weights for each dredge activity indicate the share of total energy consumed by that activity (the independent variables); for example, for the Markham, time spent traveling to and from the dump consumes more energy than time spent pumping and turning. Thus, in the Markham's case, if a given project could have "to and from dump time" reduced by 183 hrs (the value of one standard deviation), total energy consumption for the project would decrease by around 4400 MBtu (0.51 times the value of one standard deviation).

Operational time factors play a major role in explaining the variance, which supports the choice of MBtu/hr as the suitable measure for hoppers. If the amount dredged, in-place density, or number of loads would be evident enough (statistically significant) in the regression to explain the large variances, the choice of MBtu/Kcu-yd might have been appropriate. Since this did not occur, the MBtu/Kcu-yd measure is not suggested for the hoppers.

Thus, the most suitable measure for all dredge types appears to be MBtu/hr, although either MBtu/hr or MBtu/Kcu-yd could be used for dustpans. However, it has not been confirmed whether there is enough correlation between energy consumed and measures of time and productivity to warrant the choice of a measure (or measures) for nonhopper dredges.

Table 5

Stepwise Regression Summation for Hopper Dredges

Dredge	R^2	Significant Variables	Beta Weight
Wheeler		(Insufficient data)	
McFarland		(None at the .05 or .1 level)	
Markham	.99	To and from dump time	0.51
		Number of loads	0.32
		Pumping and turning time	0.21
Yaquina	.98	Pumping and turning time	1.23
		Dump time	-0.29

Bivariate Correlation Analysis

Bivariate correlations were calculated between energy consumption and other key variables that related to either operation time or material dredged. Correlations of this type are useful in explaining which variables are most responsible for changes in the dependent variable.

Quantitative results are given in Appendix A and summarized in Table 6. No correlation analysis was possible for the Wheeler because only two data sets could be obtained during this study.

The reason for no significant correlations between energy consumption and operational variables for the cutterheads is unclear. Part of the problem could have been the small data sets as well as the data's questionable reliability. Although there were no significant correlations for the cutterheads in terms of energy consumption, significant correlations were found for these dredges between the amount dredged and effective time (see Appendix A). The cutterhead's operational characteristics are such that considerably more energy would be expected to be consumed during effective time operations than during ineffective time operations. For hopper dredges, the difference between energy consumed during effective versus ineffective time operations would be less. In the dustpans' case, the Jadwin shows correlation with productivity measures, whereas the Potter shows correlation with operational time (at the less conservative level of 0.1).

At this point in the analysis, it still appears that MBtu/hr is the most suitable measure for the hoppers. In addition, it is still the best candidate for the cutterheads because of the smaller variances. For dustpans, the choice is still unclear because of the Jadwin's correlation with productivity and Potter's correlation with operational time. However, a choice of MBtu/Kcu-yd would lead to two different baseline measures of energy consumption for dredges; this could be confusing in setting and monitoring energy goals for the dredge fleet. Although it may not be difficult to develop a reasonable causal model to justify the use of different measures for different dredge types, it could be argued that the choice of a single measure would be more efficient. Furthermore, using the MBtu/hr measure for dustpans would not represent a major sacrifice in overall ability to monitor energy consumption.

Table 6

Highest Energy Correlated Variables

Dredge	Type*	Significant Correlates
McFarland	H	Operational time, ineffective time
Markham	H	Operational time, effective time
Yaquina	H	Operational time, lay time
Thompson	C	(None at the 0.05 or 0.1 level)
Ste. Genevieve	C	(None at the 0.05 or 0.1 level)
Jadwin	D	Advance, amount dredged
Potter	D	Operational time (at the 0.1 level)

*H = hopper, C = cutterhead, D = dustpan.

Discussion of Results

The statistical analyses were conducted to determine which baseline measure would best fit Corps needs in establishing energy conservation goals. Two measures, MBtu/hr and MBtu/Kcu-yd, were determined to be suitable. The ANOVA suggested that variances associated with these two measures are the same for dustpans, but only for the case of MBtu/Kcu-yd are means also the same. This implies that if MBtu/Kcu-yd were chosen as the measure for dustpan dredges, only one value could be stated for both dredges. Regression and correlation analyses indicated that operational time is the proper independent variable for the hoppers; the correlation analysis indicated that the amount dredged should be used for the Jadwin and operational time should be used for the Potter. The small variance indicated that operational time should be the choice for cutterheads.

Ideally, the measure should be one that, statistically, has the same underlying distribution, a small variance, and qualitatively explainable sources of variance. Table 7 summarizes the findings about these three criteria for each dredge type.

Since no one measure satisfies all the criteria (except for MBtu/Kcu-yd for the Jadwin and MBtu/hr for the Potter at the less conservative 0.1 level), the measure that satisfies the most criteria will be chosen. Hence, MBtu/hr is the measure of choice for hoppers and cutterheads. The measure for dustpans can still be either MBtu/hr or MBtu/Kcu-yd; however, it is recommended that MBtu/hr be selected and that progress be monitored carefully to determine if it remains the measure of choice. This means data must be collected and analyzed at regular intervals to determine which measure satisfies the criteria best.

If MBtu/hr is used as the baseline measure, a more detailed analysis into time-related sources of variance is suggested. The time-related variance sources for each dredge can be looked at separately because of the small number of vessels in each category.

Table 7

Summary of Statistical Analysis

	Hopper			Cutterhead			Dustpan		
Measure*	1	2	3	1	2	3	1	2	3
Same dist. (equal var.)**	N	N	Y	Y***	Y***	Y	Y	Y	Y
Small var.	N	Y	N	N	Y	N	N	Y	Y
Understand sources of variance	N	Y	N	N	N	N	N	Y+	Y++

*Measures: 1 = MBtu/Ehr, 2 = MBtu/hr, 3 = MBtu/Kcu-yd
**Y = yes, N = no.
***No at the less conservative 0.1 level.
+For the Potter at the 0.1 level.
++For the Jadwin.

Time-Related Sources of Variance

The choice of a time-related measure in the previous analysis makes it important to examine the time distributions for activities comprising dredge operations. Time is recorded over two general categories: effective working time and noneffective working time. Effective time involves the actual dredging process and includes pumping, turning, traveling to and from a dump site, and dumping (pumpout). Noneffective work time includes activities that support effective time but that are not part of the actual dredging process (e.g., transferring the plant, maintenance, and scheduling). Table 8 lists noneffective dredging activities.

To examine how dredging time is distributed, the dredges' monthly reports were analyzed. Monthly reports provided a consistent timeframe for comparisons between dredges. In addition, all time values were converted to percentages of total operations time for each dredge and the mean averages of these values were recorded for further consistency. The dredges Wheeler and Thompson were excluded from the analysis because of too little data.

Time distribution was analyzed to help establish goals for improving dredge efficiency and productivity. In addition, this analysis helps clarify the sources of variance in the baseline measure. A time distribution analysis identifies the most time-consuming activities and indicates where effort, in the form of new technology or operation and maintenance (O&M) strategies, could bring the greatest overall improvements.

Table 8

Noneffective Time Dredging Activities

Nonhopper	Hopper
Handling pipeline	Taking on fuel/supplies
Handling anchorline	To and from wharf
Clearing pipeline	Loss due to natural elements
Clearing cutter/suction head	Loss due to traffic
Waiting for scows	Loss due to bridges
To and from wharf	Minor operating repairs
Changing location of plant	Transferring between work
Loss due to natural elements	Lay time
Loss due to passing vessels	Fire drill
Shoreline work	Miscellaneous
Waiting for booster	
Minor operating repairs	
Waiting for attendant plant	
Making up tows	
Transferring plant	
Lay-off shift/Saturdays	
Sundays and holidays	
Fire drill	
Miscellaneous	
(De)mobilization	
Soundings	
Taking on fuel	

Activities Distribution for Hopper Dredges--Effective Working Time

The Markham and the McFarland have consistent ratios of effective dredging--around 75 percent (Table 9). The Yaquina has an effective work ratio of only 49 percent, probably because it is a new Corps vessel, and it takes considerable time to operationally "break in" a new vessel and its crew.

Traveling to and From Dump. The highest ratio value for effective working time (ranging 24 to 36 percent) is spent on traveling to and from a dumpsite. This is mainly because the limited availability of dumpsites requires that a lot of time be spent conveying sediments to the dumpsite and returning to the dredge site. For example, the dredge McFarland has had to travel up to 30 miles to reach its dumpsite for certain projects.

Pumping. Dredge pump operation is relatively consistent (ranging from 15 to 26 percent), with slight variances resulting mainly from the dredged material's density and hopper capacity.

Turning/Hookup. The time spent turning the vessels is consistently low for the McFarland and the Yaquina, but relatively high for the Markham (9 percent). The Markham is forced to take considerable time easing up and maneuvering around pumpout locations at diked disposal sites; it also works smaller projects requiring more turns per cut.

Table 9

Effective Time Distribution for Hopper Dredges (Percent)

Effective Time Activity	Dredge Markham	McFarland	Yaquina
Dredging	15	26	20
Turning/hookup	9	5	2
To and from dump	30	36	24
Dumping (pumpout)	19	5	3
Total effective time	73	72	49

Dumping. The Markham spends much time dumping dredged material (19 percent). This is probably because the Markham must pump out at select dump locations; the other dredges can use open dumping techniques at select sites.

Activities Distribution for Hopper Dredges--Noneffective Working Time

In the noneffective working time data (Table 10), the dredge Yaquina is seen to have a high value (51 percent). This is probably because of the vessel's newness and the bad weather delays in various working locations. Overall, however, only three activities seem significant in terms of time distribution.

Lay Time. The major time-consuming activity that overlaps all dredges is lay time, ranging 5 to 30 percent. "Lay time" is the period of time when, for various reasons (e.g., scheduling, holidays), the dredge is not operating. The Yaquina shows a considerable amount of lay time, which may result partly from the fact that the vessel is new and many operational and scheduling problems must be handled. Although lay time appears under "noneffective time" on the reporting forms, it is not part of the chargeable rental time.

Transferring Between Works. Another major time-consuming activity for the dredges is the transfer between job sites. Like the nonhopper dredges, hopper dredges work primarily at sites for which sediment buildup has become critical. This results in the dredges' traveling from site to site, sometimes over long distances.

Loss Due to Opposing Natural Elements. This loss of time is associated mainly with climate, weather, and sea/river conditions. The Yaquina and the McFarland each show 4 percent losses to natural elements.

Activities Distribution for Nonhoppers

The distribution of effective and noneffective time is very consistent for all three nonhopper dredges. Table 11 shows that all three vessels were operating effectively about 60 percent of the total operations time. The remaining 40 percent, which is the noneffective time, consisted of activities that reflect some interesting patterns.

Table 10

Noneffective Time Distribution for Hopper Dredges (Percent)

Dredge					
Markham		McFarland		Yaquina*	
Lay time	18	Transfer location	6	Lay time	30
Traffic	2	Lay time	5	Natural elements	12
Transfer location	2	Natural elements	4	Transfer location	4
Other	5	Other	13	Other	5
Total Ineffective Time	27		28		51

*The Yaquina has no time officially designated as "cessation."

Table 11

Activities Time Distribution for Nonhoppers (Percent)

Dredge					
Jadwin		Potter*		Ste. Genevieve	
Minor repairs	19	Passing vessels	15	Natural elements	6
Miscellaneous	5	Change location	4	Minor repairs	6
Clear suction head	4	Transfer plant	4	Mobilization	6
Change location	3	Clear suction head	3	Transferring plant	5
Passing vessels	3	Miscellaneous	3	Passing vessels	4
Other	6	Other	7	Other	13
Total Effective Time	60		64		60
Total Noneffective Time	40		36		40

*Minor repairs for the Potter probably have been recorded in different categories.

Passing Vessels

The one time-loss activity common to all three dredges is the breaking for passing vessels. These nonhopper dredges work mainly on the Mississippi River, which has heavy traffic. Since the dredges discharge through long lengths of pipeline (800 to 2500 ft [267 to 833 m]), there is a frequent need to break the pipeline and allow passing vessels through. This halts dredging operations and reduces overall productivity. The time differences between dredges generally depends on where they are operating. For example, the dredge Potter operates on the Mississippi River near the confluence of the Missouri and Illinois Rivers. This area of heavy traffic demands frequent breaking for passing vessels, which is reflected in a time distribution ratio of 15 percent.

Minor Repairs and Miscellaneous

A relatively large amount of time is spent on minor repairs and miscellaneous activities. This is especially evident for the dredge Jadwin (24 percent). However, this distribution is not unusual as these two categories include a broad range of activities. Also, the plant's age influences the time spent on minor repairs; in this case, all three dredges were built in the early 1930s and need constant maintenance. Moreover, certain dredge parts are becoming increasingly difficult to obtain, causing time delays when replacement parts are needed.

Changing Plant Location

The process of transferring plant is time-consuming, especially for the dredges Potter and Ste. Genevieve. These pipeline dredges have extensive attendant plants including tenders, barges, derricks, and launches, which makes plant transfer a complex operation. The time spent relocating the plant is partly a result of the "firefighting" technique of dredging; that is, dredging sites are selected mainly based on critical need, with priority given to areas of the river where sediment buildup mandates immediate attention. Again, this approach results in less than optimal efficiency.

Clearing the Cutter or Suction Head

Clearing the cutter or suction head is a time-consuming activity for the dredges Potter and Jadwin. The time needed depends on the size of the dustpan dredge's suction head as well as on the depth of cut and type of material being dredged.

Improving Baseline Data and Goal Monitoring

The Corps' ability to monitor energy goal achievement will only be as good as the data used in calculating the performance measure. Since most individual conservation opportunities result in small percentage changes, the ability to monitor performance depends greatly on the data's accuracy. Inaccurate, inconsistent, or insufficient data are likely to produce results with large variances that overwhelm the relatively small efficiency improvements being monitored. An effort has been made to identify ways of improving the data base; the following recommendations are strongly urged for future data collection.

Consistency of Data Collection

During the analyses, data were found to be inconsistent, with some districts using different dredge reporting forms. If goals are to be monitored accurately, it is important that the data be recorded in a consistent way. This will require USACE to adopt standard reporting forms for all districts and to insist that these forms be completed accurately by all districts.

Collection Frequency

Since the most consistent data come from monthly data reporting forms, it is recommended that such reports be generated for each dredge in addition to the daily, project, and other reporting periods. This will give a reasonable number of data points for analysis and will show the gross changes in operations over consistent time periods.

Reporting Accuracy

The Corps' current reporting procedures, though useful for monitoring dredge operations, are not necessarily optimal for monitoring energy consumption. However, specific determination of energy consumed during the reporting period is important. In particular, a more accurate linkage is needed between the amount of fuel consumed and the dredging activity during the specific reporting period. For some dredges, this linkage is not made routinely within the current reporting procedures. In addition, future operations may require an understanding of the material dredged. Therefore, more accurate and frequent measures of in-place density are recommended.

Another important consideration is that two dredges (Wheeler and Essayons) are newly constructed and have only limited data at this time. It is important that good data be collected and analyzed for these dredges so that baseline energy consumption levels and goals can be established.

Finally, since the recommended MBtu/hr baseline measure is time-related, emphasis should be placed on insuring accuracy in the time allocations reported for various operating activities--for example, the time required for dumping, lost to passing ships, or otherwise spent. Accurate information of this type will allow job- and mission-related changes in energy consumption to be isolated from goal-related changes in energy efficiency.

Monitoring Consumption Changes

Monitoring energy goal achievement will require that year-to-year changes in aggregate consumption be isolated into two components. One component would reflect (and adjust for) the increase or decrease in overall energy consumption associated with changes in mission or operating environment. The very high levels of explained variance obtained in the regression analyses suggest that, with accurate data, it should be possible to account statistically for these mission and operational factors.

The second component of the year-to-year differences would be an accurate reflection of changes in energy efficiency associated with the types of technical and management conservation strategies identified in this study. Without this dual approach, the increased scope in the dredging mission could make energy consumption appear to increase, despite successful implementation of cost-effective conservation strategies. Thus, it is both vital and feasible that mission-based energy changes be isolated carefully from those attributable to efficiency changes. Information from the preceding analysis can be used to help determine if the conservation strategies selected have been successful. In particular, if operation times change greatly, they may well have direct effects on energy consumption and goal attainment.

Choice of a Suitable Measure

Based on this analysis, the best single measure for all dredges is MBtu/hr. For this choice, each dredge will have a unique value expressed in MBtu/hr and a range of goals based on various conservation strategies that applies only to its characteristics. As additional data are gathered, analyses appropriate to each dredge should serve to further explain the variance in energy consumption, making prediction of the energy needed on a given project more accurate for each dredge. This, in turn, should allow the effects of energy conservation options to be determined more accurately. Consistent, reliable data gathering and analysis should substantiate the baseline measure's suitability.

3 CONSERVATION POTENTIAL IN THE CORPS' DREDGE FLEET

Technical and management options were analyzed for potential in increasing the energy efficiency of Corps dredging operations. Appendix B gives details for the 10 most promising energy conservation strategies in terms of potential energy savings and applicability to specific Corps dredges.

Approach and Data Sources

Potential energy-saving strategies were assessed by reviewing the literature dealing with improvements in dredging technology and management approaches. Several suppliers to the dredging industry were also contacted for product information and documentation for claimed efficiency improvements. In addition, the preliminary conclusions about potential energy-saving strategies were reviewed by experts at the Marine Design Center in Philadelphia and at the Water Resources Support Center--Dredging Division, Fort Belvoir, VA.

The literature review and discussion with experts identified several technology-based options as well as some operations- and management-related options for consideration. These individual options (or in some cases families of options) were evaluated based on the relative size of the efficiency gains they could provide. They were then judged for each dredge expected to remain in the minimum fleet during the next few years.

It should be recognized that it is very difficult (if not impossible) to make point estimates of energy efficiency gains that might be expected by applying the various options to specific dredges or dredge classes. The problem is twofold. First, most efficiency gains claimed for new technologies or management approaches are not well documented in the literature. This means reliable point estimates cannot be made about their effectiveness when applied to specific ships or dredging conditions. These determinations would require detailed feasibility and engineering-economic studies (for options that look promising enough to pursue). Such studies would be very expensive. The best that can be hoped from the level of analysis available to this project is to establish broad ranges of potential efficiency gains should the options prove feasible in specific cases.

The second related problem is that most options available do not have general applicability, but depend greatly on the context in which they operate. For example, older diesel engines can be retrofit to achieve efficiency gains as high as 15 percent. But whether the actual gains are 15 percent or zero percent depends on the specific condition and design of the old equipment. Moreover, the new hopper dredges have been designed with state-of-the-art equipment, leaving only limited opportunity for significant cost-effective technological improvement. For some older dredges, the expected life is short enough that large investments in efficiency improvements may not prove cost-effective.

These considerations all limit the ability to pinpoint specific efficiency improvements. Therefore, goals have been developed according to ranges of potential improvement (subject to further engineering-economic analysis), and in terms of if/then statements (e.g., if the engine on dredge X were given treatment Y, efficiency gains of 5 to 15 percent might be expected).

Appendix B discusses the 10 most promising strategies using Dredge Energy Strategy forms developed for consistent display and discussion. Options excluded are (1) those with only very small expected energy savings (such as quick disconnect pipeline couplings) and (2) those dependent on technologies not yet ready for actual use (for example, fuel emulsions and catalysts). The 10 strategies are:

- Steam to diesel conversion
- Performance modifications
- Fuel substitution
- Submersible pumps
- Suction relief valves
- Production meters
- Hull and digging head positioning
- Head design
- Hull coatings
- Efficient use and maintenance of propellers.

Dredge-Specific Energy Savings Potential

Chapter 2 findings on baseline measures were combined with the dredge-specific technical strategies to estimate potential energy savings if all strategies were implemented. In combining the strategies, it was assumed that they are essentially additive, that is, that including the first strategy will not significantly affect the expected percentage savings from the second strategy, and so forth. As a result of this assumption, the energy savings given here represent the maximum potential savings expected from the combined strategies. Actual savings could easily be less than this value, depending on dredge-specific and operational factors. The assumption that the savings are additive as well as the actual applicability and energy savings for each strategy would require additional engineering-economic analyses before implementation could be recommended.

Figure 2 shows how implementing the technical strategies could influence the MBtu/hr value for a dredge. The "stairstep" pattern results from applying the technical strategies with potential energy savings for a particular dredge. The maximum potential savings has been calculated as a percentage reduction below the baseline values reported for each dredge (Table 3). It should be stressed that baseline numbers for several of the dredges have been constructed from relatively limited data. Ongoing data analysis and improved data collection and reporting systems will upgrade the accuracy of dredge energy baselines. For now, these values represent the best available estimates of dredge performance.

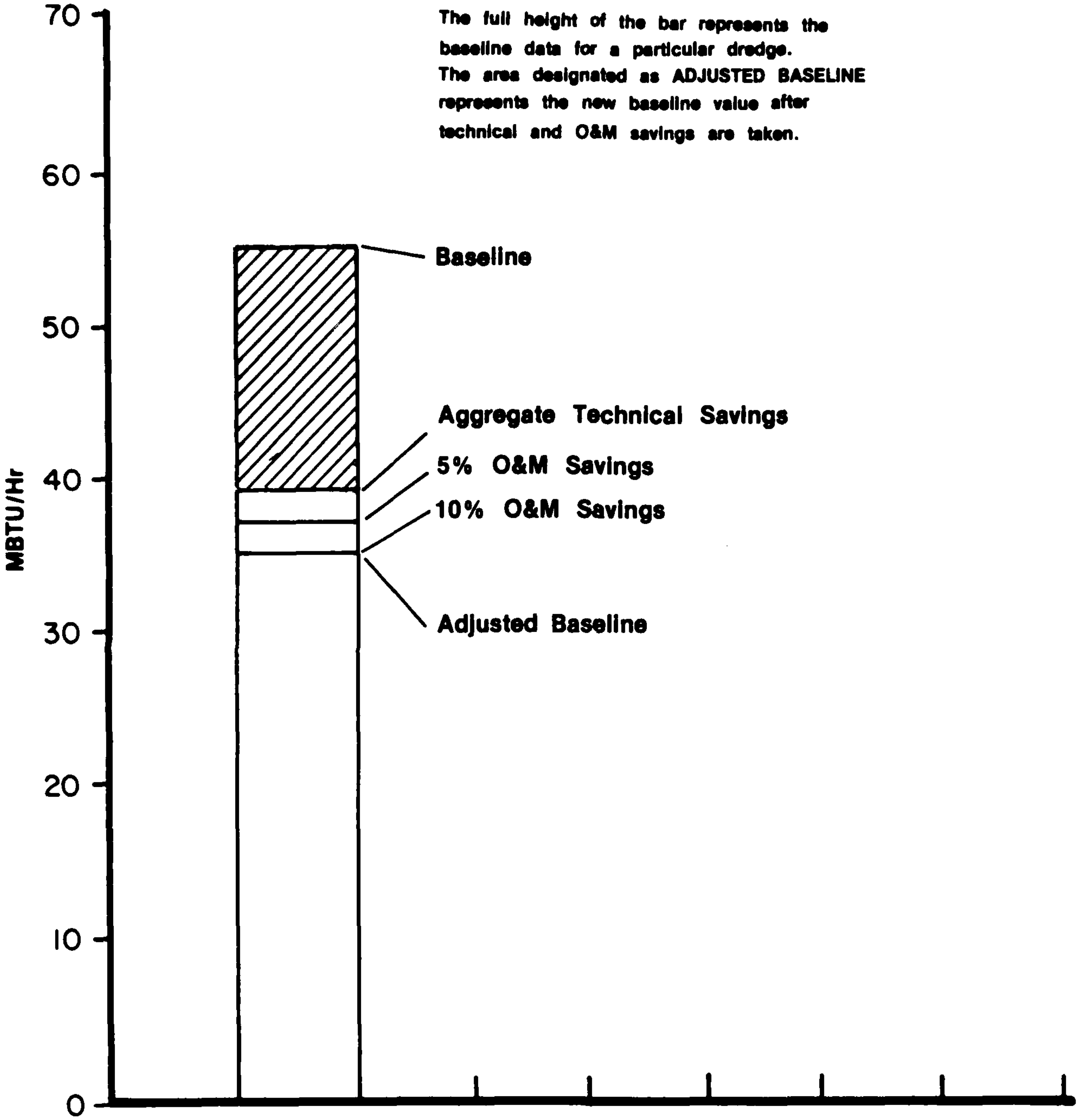

Figure 2. Technical conservation strategies applied to the dredge Markham.

Wheeler

Four technical conservation strategies potentially apply to the hopper dredge Wheeler, which has a baseline energy consumption value of 53 MBtu/hr. As Table 12 shows, these strategies include the addition of head optimization and hull coatings. The maximum potential energy savings is estimated to be 8 percent.

Essayons

The hopper dredge Essayons was not covered in this analysis because no data were available. However, it is likely that this dredge could achieve some energy savings if hull coatings were installed and suction heads were optimized.

McFarland

Six technical conservation strategies potentially apply to the hopper dredge McFarland, which has a baseline energy consumption value of 29 MBtu/hr. Table 12 shows these to include engine performance modifications, submersible pumps, production meters, head optimization, hull coatings, and propeller maintenance. The maximum potential energy savings from these strategies is estimated at 22 percent.

Markham

Six technical conservation strategies potentially apply to the hopper dredge Markham, with a baseline energy consumption value of 18 MBtu/hr. These include engine performance modifications, submersible pumps, head optimization, hull coatings, and propeller maintenance (Table 12). The maximum potential energy savings from these strategies is an estimated 22 percent.

Yaquina

Four technical conservation strategies have potential use on the hopper dredge Yaquina, for which the baseline energy consumption value is 13 MBtu/hr. As Table 12 shows, these include the addition of submersible pumps, head optimization, and hull coatings. The maximum potential energy savings estimated from these strategies is 14 percent.

Thompson

Six technical conservation strategies potentially apply to the cutterhead dredge Thompson, which has a baseline energy consumption value of 7 MBtu/hr. These are engine performance modifications, suction relief valves, production meters, positioning equipment, hull coatings, and propeller maintenance. The maximum potential energy savings from these strategies is estimated at 23 percent.

Table 12

Energy Savings by Dredge and by Technical Strategy

Dredge	Base-line MBtu/hr	Steam to Diesel	Perfor-mance Modifi-cation	Convert to Coal Slurry	Submer-sible Pumps	Suction Relief Valves	Produc-tion Meters	Position-ing Equip-ment	Efficient Head Design	Hull Coatings	Propeller Use & Mainte-nance	Adjusted Base-line	Tech-nical Savings (%)
Wheeler	53								49.56	48.81		48.81	8
McFarland	29		27.12		25.35		24.97		23.35	23.00	22.65	22.65	22
Markham	18		16.83		15.74		15.50		14.49	14.28	14.06	14.06	22
Yaquina	13				12.16				11.36	11.19		11.19	14
Thompson	7		6.55			6.12	6.03	5.94	5.55	5.47	5.39	5.39	23
Ste. Genevieve													
A	33	20.79				19.44	19.15	18.86	17.63	17.37		17.37	47
B	33			22.11		20.67	20.36	20.06	18.75	18.47		18.47	44
C	33		30.86		30.86	28.85	28.42	27.99	26.17	25.78		25.78	22
Jadwin													
A	59	37.17				34.75	34.23		32.01	31.53	31.05	31.05	47
B	59			39.53		39.96	36.41		34.04	33.53	33.03	33.03	44
C	59		55.17			51.58	50.81		47.50	46.79	46.09	46.09	22
Potter													
A	40	25.20				23.56	23.21	22.86	21.37	21.05	20.74	20.74	48
B	40			26.80		25.06	24.68	24.31	22.73	22.39	22.05	22.05	45
C	40		37.40			34.97	34.44	33.93	31.72	31.25	30.78	30.78	23

Ste. Genevieve

Five technical conservation strategies have potential application on the 33-MBtu/hr cutterhead dredge Ste. Genevieve. These are engine modifications, suction relief valves, production meters, positioning equipment, and hull coatings (Table 12). The maximum potential energy savings estimated from these strategies is between 22 and 47 percent, depending on which of three alternative engine modifications are considered. Modification of the existing steam plant is rated as a strategy producing 3 to 10 percent savings; conversion to a coal-slurry fuel mixture could save 15 to 45 percent of current petroleum consumption (though not of overall energy consumption); and conversion from steam to diesel type could cut overall energy consumption by roughly 37 percent.

Jadwin

Four technical conservation strategies potentially apply to the dustpan dredge Jadwin, with a baseline energy consumption value of 59 MBtu/hr. As Table 12 shows, these are engine modifications, suction relief valves, production meters, hull coatings, and propeller maintenance. The maximum potential energy savings estimated from these strategies is between 22 and 47 percent, depending on which of three alternative engine modifications are used. Modification of the existing steam plant is rated as a strategy producing 3 to 10 percent savings; conversion to a coal-slurry fuel mixture could save 15 to 45 percent of current petroleum consumption (though not of overall energy consumption); and conversion from steam to diesel type could cut overall energy consumption by roughly 37 percent.

Potter

Five technical conservation strategies have potential use on the 40-MBtu/hr dustpan dredge Potter. These include engine modifications, suction relief valves, production meters, positioning equipment, hull coatings, and propeller maintenance (Table 12). The maximum potential energy savings estimated from these strategies is between 23 and 48 percent, depending on which of three alternative engine modifications are used. Modification of the existing steam plant is rated as a strategy producing 3 to 10 percent savings; conversion to a coal-slurry fuel mixture could save 15 to 45 percent of current petroleum consumption (though not of overall energy consumption); and conversion from steam to diesel type could cut overall energy consumption by about 37 percent.

4 MANAGEMENT STRATEGIES FOR ENERGY CONSERVATION

Overview

Management strategies are related to planning and execution of the Corps dredge operating mission. There appear to be several areas in which management changes could produce energy savings.

A central issue in proposing energy-saving management strategies is the difficulty in assigning actual savings to any one procedural change. In contrast to many of the technical strategies, the literature contains far less discussion about management-based options and little or no empirical data testing approaches that are discussed. Also, it is difficult to identify the tradeoffs with other productivity elements such as labor effectiveness, and with constraining factors such as environmental regulations.

Energy Savings Potential

Any strategy for conserving energy by changing management procedures must be weighed against other Corps mission-related priorities such as gross productivity, maintenance of environmental quality, and others. This is not to suggest these priorities are mutually incompatible; in fact, events of the past 10 years have reinforced the importance of energy management in a fiscally responsible operation. Although technical strategies can be applied on a ship-by-ship basis, they alone may not fully achieve potential savings because of other use-related mission changes. Thus, it is essential that technical strategies be adopted concurrently with management strategies to provide an integrated approach to energy management.

For most technical energy conservation strategies, the potential energy saving accrues from reducing the overall quantity of energy required to perform a certain part of the dredging operation. For example, an engine performance modification will translate directly into fewer MBtus required for each hour of operation. In contrast, management strategies are designed to heighten sensitivity toward energy-based productivity issues related to operations and management. The potential savings will be through reductions in total yardage or in dredge total rental time. Since the analysis in Chapter 2 documents the relationship between yardage and time-based measures, it is reasonable to state that in using an energy measure of MBtu/hr, management strategies would increase the dredging operation's time-based efficiency and would result in a lower MBtu/hr value.

To accommodate the variety of management options, it has been found convenient to cluster the strategies around four major areas with each category broadly defining one component of dredge operations. Although it is hard to attribute an exact energy savings to any one strategy, it is reasonable to assume that a range of savings (i.e., 0 to 5, 5 to 10 percent) will accrue as a larger aggregate set of management strategies are adopted. Adoption of any of the following strategies will first require an analysis at the District level. However, these strategies also could be researched and implemented selectively on a Corps-wide basis. It should be emphasized that some of the Districts already practice these strategies informally. In such cases, formalizing these procedures and adopting other strategies should produce an energy savings.

Job Scheduling

In most cases, job scheduling is based largely on historical information, and though it provides a good "first cut" at dredge jobs, this approach cannot respond effectively to unexpected natural events such as flooding. Some areas for potential study include:

- Formalizing the connection between hard operational input, such as before-and-after surveys, and historical data
- Improving hydrologic performance models for dredging Districts to better predict stormflow and baseflow patterns given various weather scenarios
- Identifying the variation in the time effectiveness of dredging overdepth versus repeated visits to a particular site
- Insuring that the job sequence the dredges cover in a season is the most efficient, given some constraints from environmental concerns
- Trying to minimize the distance to dump site as best as possible, given environmental considerations; finding suitable new dump locations.

Plant Selection

Although PL 95-269 has reduced the number of Corps plant available, matching the right piece of plant to a particular job is important in dredging operations. Items to consider include:

- Matching dredge performance to the job size and to in-situ densities, with the result of minimizing total time on the job
- Carefully planning inter-District dredge transfers, and considering alternative basing options.

Dredging Procedures

Once a dredge is onsite, several operations begin that are geared toward minimizing the amount of time required. However, in a program for energy efficiency, the following steps could be taken:

- Improving setup and takedown procedures, including floating plant configuration
- Improving the use of positioning aids and monitoring the cut's accuracy
- Optimizing the dredging load curve
- Minimizing downtime.

Energy as a Planning Criterion

The savings from management strategies will depend to some extent on current procedures in each District. Although energy management has been a Corps priority for several years, facilities have been emphasized. Therefore, this research is among the first energy management information directed toward process consumption in Civil Works. For example, energy considerations are absent from the planning checklist in EM 1110-2-5025,[4] although they are implicit in other economic objectives. It should be possible to achieve meaningful energy savings for the Corps plant by specifically increasing sensitivity to energy aspects of project planning.

Potential Energy Savings by Dredge Type--Summary

The maximum potential energy savings were summarized on a ship-specific basis by combining the effects of the technical- and management-based strategies just discussed. Figures 3 through 6 show the combined contribution of technical and management options to the overall energy savings. Estimated maximum potential savings are shown for all technical strategies that apply to the dredge as well as management savings corresponding to 5 and 10 percent levels of improvement (after accounting for the technically based savings). Figure 3 provides a detailed legend for interpreting elements of the bar charts. The potential energy savings for each hopper, cutterhead, and dustpan dredge are shown in Figures 4, 5, and 6, respectively.

The next step was to suggest processes the Corps might consider in translating these maximum potential energy savings estimates into energy management goals for dredging.

[4]Engineer Manual (EM) 1110-2-5025, Engineering and Design, Dredging and Dredged Material Disposal (U.S. Department of the Army, Corps of Engineers, Office of the Chief of Engineers, 1983).

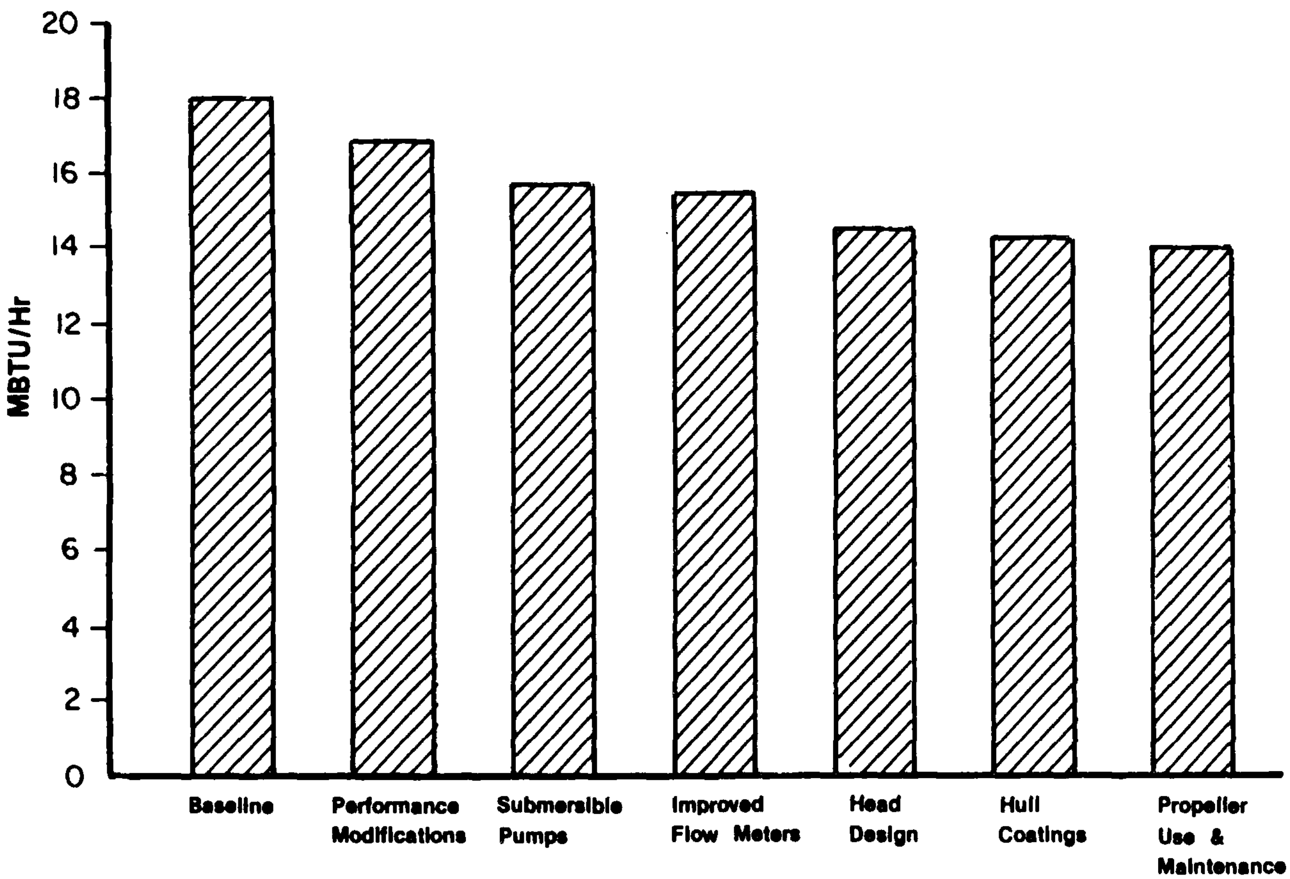

Figure 3. Interpreting bar charts for estimated potential energy savings by dredge type.

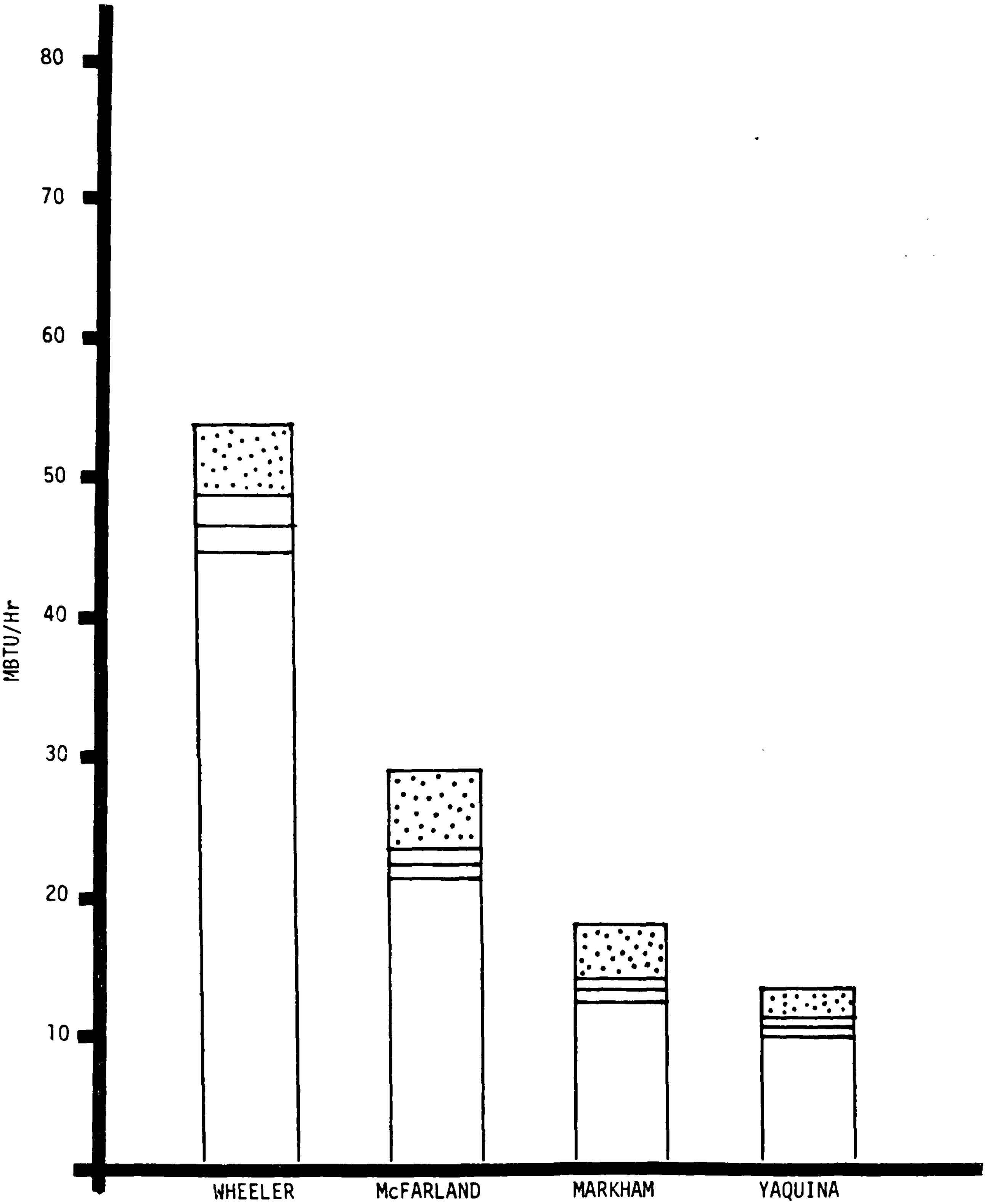

Figure 4. Hopper dredge energy savings.

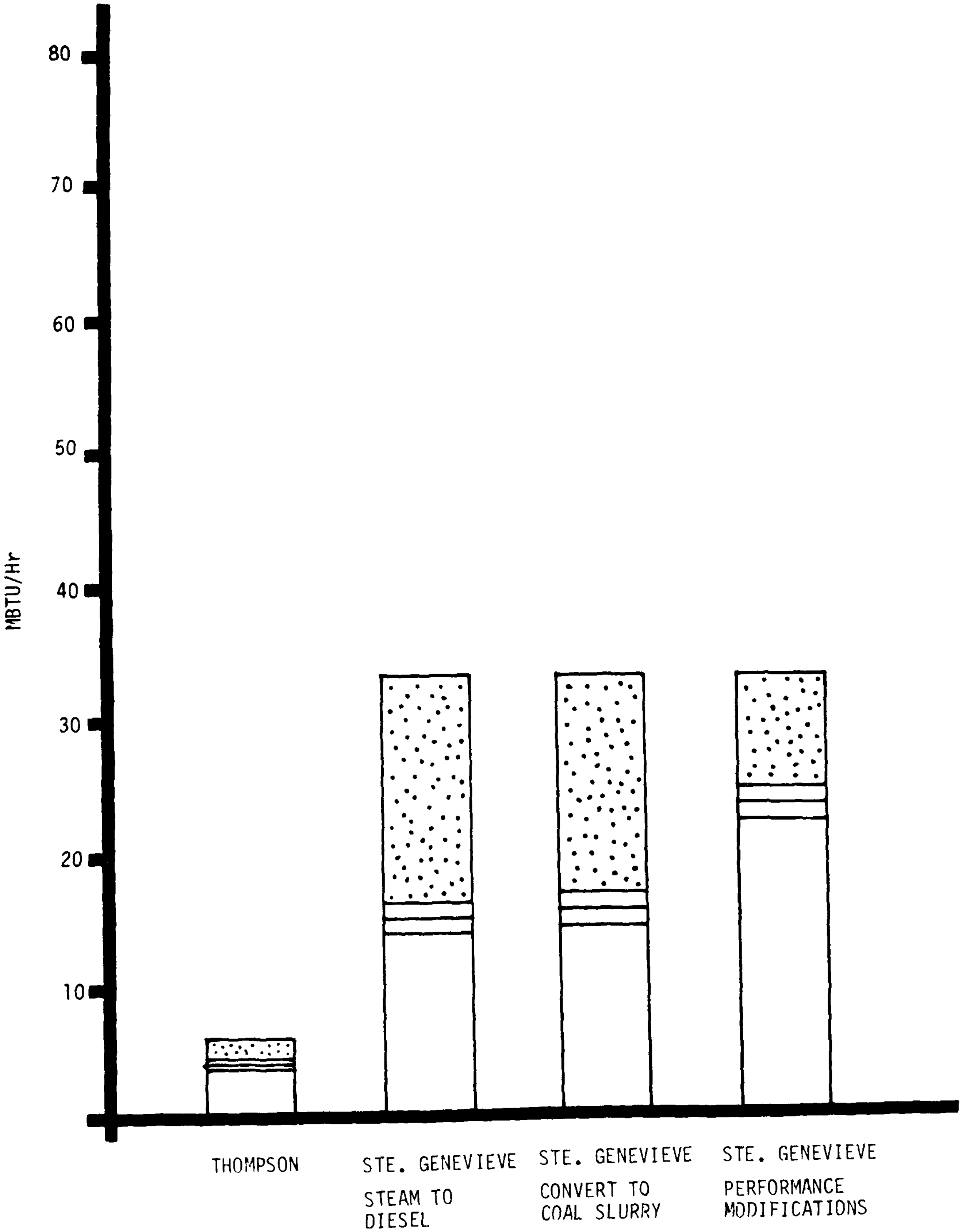

Figure 5. Cutterhead dredge energy savings.

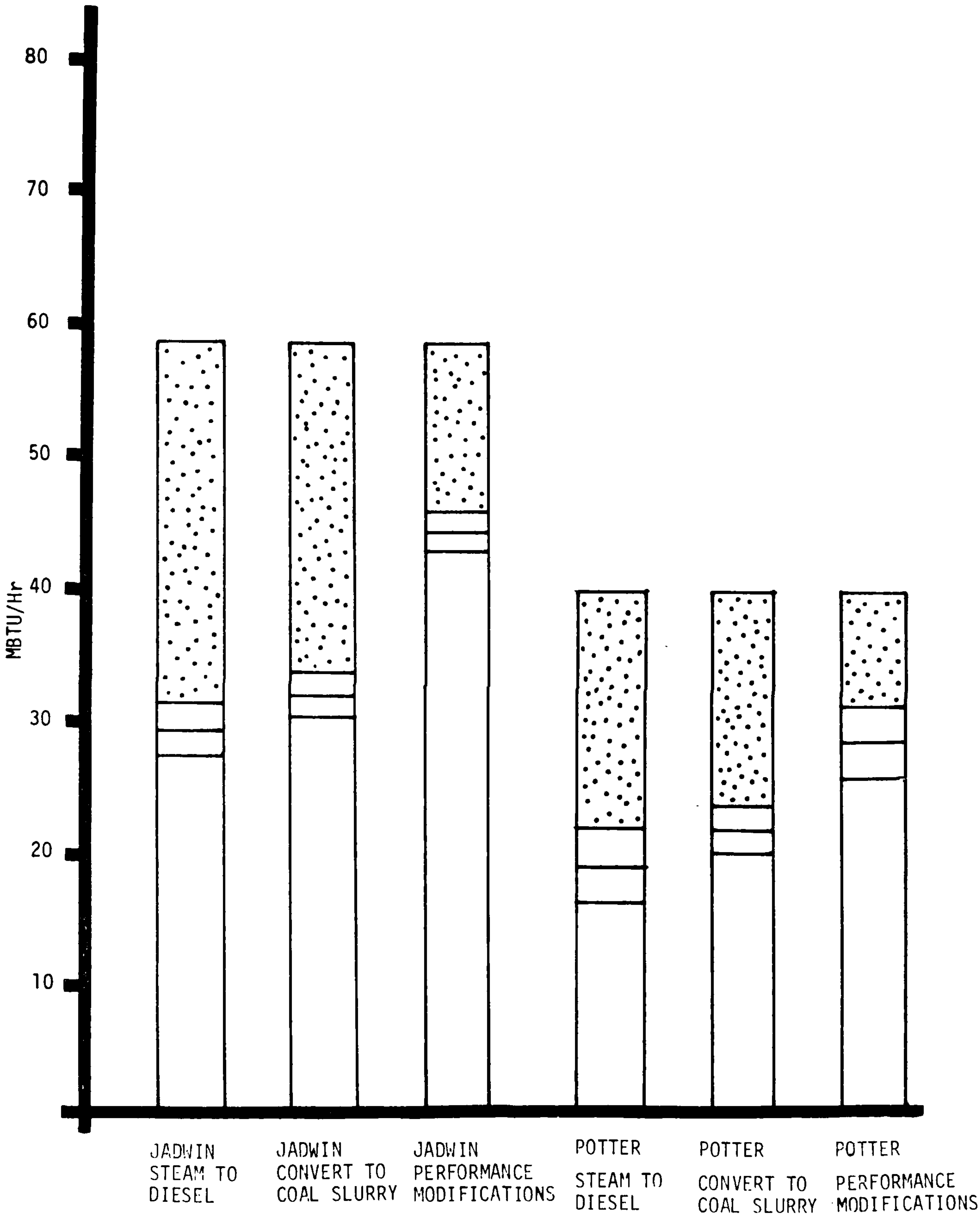

Figure 6. Dustpan dredge energy savings.

5 USING STRATEGIES TO DEVELOP CORPS ENERGY GOALS

Approaches

Several important distinctions must be recognized when discussing energy goals for dredging. First, the analysis of potential energy conservation opportunities (both technical and management) provides estimates of maximum potential energy savings. It would be unrealistic to expect savings at those levels to be achieved cost-effectively in the short term or even the long term. Not all potential opportunities will prove technically practical or cost-effective when examined within job and dredge-specific constraints.

A second distinction should be made between long-term cost-effective goals and short-term achievable goals. That is, long-term goals typically must be met through a series of incremental and practical short-term goals. In general, longer-term goals reflect an assumption that at least some opportunities available among the longer-term options will prove to be both technically feasible and economically attractive, even though they may not appear so immediately. On the other hand, shorter-term goals must be structured around much more rigid and pragmatic engineering-economic performance criteria.

Finally, a clear distinction must be made between energy goals directed toward Corps dredges and those directed toward the Corps dredging mission. At present, the Corps-owned plant only does about 25 percent of Corps dredging activities, with contract dredge operators handling the rest. Although many conservation opportunities identified earlier might apply to contract dredges, this study is limited to the Corps-owned fleet. Furthermore, only limited data are available on energy consumption by the contract dredges. Stating energy efficiency goals for the Corps dredge mission would require further research to bring contract dredges into the energy data reporting system, and to analyze their data in terms of an energy management program.

Energy Consumption Goals

Before proposing energy conservation goals for dredging, it is important to understand that the goal-setting process is inherently arbitrary. In particular, since this is the first time goals are being set to conserve energy on dredges, there is no historical basis for determining if they are likely to be achieved (i.e., reasonable). An effort has been made in this study to reduce the degree to which these goals are arbitrary by examining past energy consumption data and considering what technological options may be available to reduce energy consumption.

Based on (1) statistical analysis of the available dredge fuel consumption data and (2) estimated savings from technological improvements, energy consumption goals for the Minimum Dredge Fleet are proposed as shown in Table 13.

These goals reflect what may be feasible technologically, not necessarily what may be the most economical. The goals should be regarded as an upper limit on reduction achievable using the technical and management strategies discussed.

Table 13

Energy Consumption Goals for the Corps Minimum Dredge Fleet

Dredge	Present Baseline (MBtu/hr)	Goal (MBtu/hr)	Reduction (%)
Wheeler	53	49	8
McFarland	29	23	22
Markham	18	14	22
Yaquina	13	11	14
Thompson	7	5	23
Ste. Genevieve	33	26	22
Jadwin	59	46	22
Potter	40	31	23

6 CONCLUSIONS AND RECOMMENDATIONS

Statistical analyses have been conducted to determine which process efficiency indicator could be used as a basis in developing energy conservation goals for Civil Works dredging operations. This evaluation included descriptive analysis, analysis of variance, and two methods for assessing variance sources--stepwise regression analysis and bivariate correlation. Indicators tested were those judged most promising for goal development: MBtu/hr, MBtu/Ehr, and MBtu/Kcu-yd. Based on this analysis, the best measure for all dredge types is MBtu/hr.

Ten energy conservation technologies that apply to dredging have been identified and their projected impact on individual dredge energy consumption has been estimated.

Management strategies also have been studied to find ways of increasing dredge energy efficiency. Although it is difficult to quantify savings from improved management, the heightened sensitivity to good conservation practices should benefit an energy management program in the long term.

The technology- and management-based strategies analyzed in this study have been used to develop energy conservation goals for the Corps Minimum Dredge Fleet (Table 13). It is recommended that the proposed goals be considered in developing the Corps-wide energy management program for Civil Works.

APPENDIX A:

STATISTICAL ANALYSIS OUTPUT

This appendix contains the variable list and computer-generated output for the statistical analysis described in Chapter 2.

Variable Code

Dredge Type*	Label	Description
H,N	DRG	Dredge 1. McFarland 6. Potter 2. Wheeler 8. Thompson 3. Yaquina 9. Ste. Genevieve 5. Jadwin 11. Markham
H	CAP	Hopper capacity in cu yd
H,N	RPT	Reporting Period 4. Project report 5. Monthly report
H,N	DAT	Date reporting code in the form MMDDY MM = month DD = day Y = last digit in year
H	VR	In-place density
H,N	DRE	Amount dredged in cu yd
H	LDS	Number of loads
H	TFD	To and from dump time
H	DT	Dump time
H,N	ET	Effective time
H	LT	Lay time
H	RT	Effective time plus ineffective time
H	NT	Ineffective time
H	BBL	Barrels of oil consumed
H,N	MBTU	Million BTU equivalent of oil consumed
H,N	BTUPEH	Ratio of MBTU to effective time

*H = Hopper dredges, N = nonhopper dredges.

Variable Code

Dredge Type*	Label	Description
H	BTUPH	Ratio of MBTU to effective time plus noneffective time
H,N	DPBT	Ratio of amount dredged to MBTU
H	ANT	Noneffective time minus lay time
H	BTUPT	Ratio of MBTU to operational time
H	BTUCY	Ratio of MBTU to amount dredged in cu yd
H,N	BTUKCY	Ratio of MBTU to amount dredged in thousand cu yd
H	PTT	Pumping and turning time
N	VR	Voids ratio in the form %% M_1M_2 %% = percent of primary material M_1 = primary material code number M_2 = secondary material code number 1. Sand 4. Silt 2. Gravel 5. Other 3. Clay
N	ADV	Amount advanced in feet
N	PL	Discharge pipe length in feet
N	DPH	Average amount dredged per hour effective time
N	NT	Noneffective time minus lay time
N	OIL	Barrels of oil consumed
N	TOT	Operational time
N	APH	Ratio of amount advanced to effective time
N	BTUPH	Ratio of MBTU to operational time
N	DEP	Average depth of cut

*H = Hopper dredges, N = nonhopper dredges.

<DESC BYST VAR=5-13,15,16,25,27,29 CASES=V3:4 STRAT=V1>

Descriptive Measures <1> DRG:1 CASES=RPT:4

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.VR	10	1445.0	1981.0	1675.8	192.88
6.DRE	10	48048.	.13090 +7	.50145 +6	.32212 +6
7.LDS	10	17.000	476.00	243.30	127.60
8.TFD	10	12.000	1005.0	454.70	397.91
9.DT	10	1.0000	95.000	34.100	24.319
10.ET	10	33.000	1189.0	707.90	381.10
11.LT	10	0.	133.00	58.900	49.640
12.RT	10	57.000	1577.0	975.20	509.98
13.NT	10	23.000	697.00	267.00	179.97
15.MBTU	10	758.52	45788.	26475.	14092.
16.BTUPEH	10	13.951	52.453	38.358	12.844
25.BTUPT	10	12.100	42.158	28.542	9.5960
27.BTKCY	10	15.787	109.10	56.171	32.177
29.PTT	10	20.000	503.00	219.10	136.04

Descriptive Measures <2> DRG:2 CASES=RPT:4

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.VR	2	1450.0	1573.0	1511.5	86.974
6.DRE	2	.53135 +6	.90695 +6	.71915 +6	.26559 +6
7.LDS	2	14.000	235.00	124.50	156.27
8.TFD	2	7.0000	107.50	57.250	71.064
9.DT	2	.90000	28.660	14.780	19.629
10.ET	2	160.50	342.66	251.58	128.81
11.LT	2	0.	2.4100	1.2050	1.7041
12.RT	2	279.00	668.00	473.50	275.06
13.NT	2	118.33	325.33	221.83	146.37
15.MBTU	2	18228.	26348.	22288.	5741.9
16.BTUPEH	2	76.893	113.57	95.232	25.934

HOPPER DREDGES

25.BTUPT	2	39.444	65.943	52.694	18.738
27.BTKCY	2	29.052	34.305	31.678	3.7147
29.PTT	2	152.60	206.50	179.55	38.113

Descriptive Measures <3> DRG:3 CASES=RPT:4

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.VR	10	1476.0	2072.0	1878.9	222.84
6.DRE	10	5775.0	.32875 +6	.13100 +6	.12633 +6
7.LDS	10	7.0000	440.00	192.60	167.10
8.TFD	11	0.	362.00	86.754	111.28
9.DT	11	0.	23.500	9.4436	8.3062
10.ET	11	0.	580.00	182.28	187.08
11.LT	11	0.	312.00	112.36	111.15
12.RT	11	16.000	1044.0	376.82	342.85
13.NT	11	2.3300	426.80	197.52	159.36
15.MBTU	11	252.84	9237.5	3596.4	3252.2
16.BTUPEH	10	15.278	38.946	20.932	6.7480
25.BTUPT	11	6.4949	17.676	13.436	3.1531
27.BTKCY	10	23.037	97.280	38.410	21.533
29.PTT	11	0.	203.67	86.081	74.168

Descriptive Measures <11> DRG:11 CASES=RPT:4

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.VR	18	1222.0	1970.0	1455.2	183.46
6.DRE	18	3786.0	.91730 +6	.28899 +6	.25881 +6
7.LDS	18	3.0000	702.00	222.06	212.54
8.TFD	18	16.000	632.00	228.94	183.38
9.DT	18	3.0000	457.00	132.39	134.89
10.ET	18	22.000	1446.0	536.33	444.41
11.LT	18	8.0000	472.00	139.61	139.86
12.RT	18	93.000	2040.0	747.61	623.79
13.NT	18	44.000	629.00	211.28	184.94
15.MBTU	18	588.00	30323.	10951.	8662.7
16.BTUPEH	18	17.709	26.727	21.589	2.4970
25.BTUPT	18	8.5217	21.313	17.810	2.8314
27.BTKCY	18	19.603	155.31	56.023	38.009
29.PTT	18	3.0000	497.00	175.00	156.18

HOPPER DREDGES

<DESC BYST VAR=5-9,11-14,18,19,25 CASES=V2:5 STRAT=V1>

Descriptive Measures <8> DRG:8 CASES=RPT:5

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.ADV	4	7395.0	15925.	10330.	3809.1
6.PL	4	1534.0	3956.0	2784.8	1240.4
7.DPH	4	524.00	1000.0	789.00	196.81
8.ET	6	150.84	299.83	225.41	60.046
9.NT	6	251.00	420.00	321.50	60.428
11.MBTU	6	2857.7	4839.2	4008.2	729.70
12.TOT	6	479.00	673.00	546.91	69.300
13.APH	4	29.383	58.120	45.137	12.015
14.DRE	6	.13099 +6	.35552 +6	.25811 +6	78306.
18.BTUPH	6	4.9627	9.8941	7.4143	1.5889
19.BTUPEH	6	9.5310	28.550	19.340	7.3782
25.BTKCY	6	9.3685	31.018	17.370	7.8160

Descriptive Measures <9> DRG:9 CASES=RPT:5

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.ADV	4	6300.0	15200.	10746.	4221.6
6.PL	4	1315.0	2538.0	1669.8	581.46
7.DPH	4	961.00	1101.0	1036.5	64.216
8.ET	4	230.15	504.66	410.03	122.41
9.NT	4	164.66	432.75	256.41	123.42
11.MBTU	4	18436.	25884.	21854.	3623.9
12.TOT	4	618.74	701.50	666.45	35.497
13.APH	4	17.860	30.119	26.248	5.7187
14.DRE	4	.23176 +6	.55563 +6	.42744 +6	.13932 +6
18.BTUPH	4	28.921	36.898	32.665	3.9084
19.BTUPEH	4	40.601	83.302	57.168	18.733
25.BTKCY	4	42.249	82.723	55.322	18.942

CUTTERHEAD DREDGES

<DESC RPT VAR 5, 9,11 14,18,19,22,25 CASES=V2:5 STRAT=V1>

Descriptive Measures <5> DRG:5 CASES=RPT:5

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.ADV	5	.10800 +6	.22590 +6	.16696 +6	53986.
6.PL	5	850.00	900.00	875.00	25.000
7.DPH	5	3286.0	3378.0	3332.6	42.881
8.ET	5	312.84	536.00	409.30	92.201
9.NT	5	188.08	431.16	277.05	92.709
11.MBTU	5	34802.	47920.	40359.	5547.2
12.TOT	5	574.24	768.50	686.34	82.972
13.APH	5	279.68	481.32	405.23	74.892
14.DRE	5	.10549 +7	.18106 +7	.13652 +7	.31673 +6
18.BTUPH	5	50.277	62.355	58.906	4.9386
19.BTUPEH	5	89.403	119.57	100.52	13.209
22.DEP	5	5.3435	9.0830	6.5578	1.4557
25.BTKCY	5	26.466	35.460	30.162	3.9178

Descriptive Measures <6> DRG:6 CASES=RPT:5

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
5.ADV	5	14400.	.18530 +6	.12440 +6	68885.
6.PL	5	800.00	800.00	800.00	
7.DPH	5	1955.0	2489.0	2116.2	215.55
8.ET	5	39.160	512.33	390.68	201.24
9.NT	5	16.330	314.84	205.62	111.70
11.MBTU	4	23462.	34015.	29513.	4741.7
12.TOT	5	55.490	744.00	596.29	302.54
13.APH	5	252.74	367.72	325.02	49.099
14.DRE	5	97469.	.10544 +7	.79272 +6	.39585 +6
18.BTUPH	4	32.587	45.719	40.276	5.8369
19.BTUPEH	4	48.095	69.413	61.922	9.5480
22.DEP	5	4.3895	6.3884	5.1015	.81170
25.BTKCY	4	24.217	34.188	30.587	4.4806

DUSTPAN DREDGES

Analysis of Variance Output

```
<ANOVA OPTIONS=EQUALITY VAR=16,17.27 CASES=V3:4 STRAT=V1>

Univariate 1-way ANOVA  CASES=RPT:4

ANALYSIS OF VARIANCE OF 16.BTUPEH  N= 40 OUT OF 41

SOURCE              DF  SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF

BETWEEN              3     11285.      3761.6      50.658      .0000
WITHIN              36     2673.2      74.254
TOTAL               39     13958.      (RANDOM EFFECTS STATISTICS)

ETA= .8992  ETA-SQR= .8085  (VAR COMP= 412.76  %VAR AMONG= 84.75)

EQUALITY OF VARIANCES:  DF= 3, 257.85        F= 12.284      .0000

DRG           N    MEAN     VARIANCE    STD DEV

(1)          10   38.358     164.97      12.844
(2)           2   95.232     672.59      25.934
(3)          10   20.932     45.535      6.7480
(11)         18   21.589     6.2352      2.4970

GRAND        40   29.299     357.90      18.918

Univariate 1-way ANOVA  CASES=RPT:4

ANALYSIS OF VARIANCE OF 17.BTUPH  N= 41 OUT OF 41

SOURCE              DF  SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF

BETWEEN              3     4046.8      1348.9      39.640      .0000
WITHIN              37     1259.1      34.030
TOTAL               40     5305.9      (RANDOM EFFECTS STATISTICS)

ETA= .8733  ETA-SQR= .7627  (VAR COMP= 142.88  %VAR AMONG= 80.76)

EQUALITY OF VARIANCES:  DF= 3, 262.17        F= 11.488      .0000

DRG           N    MEAN     VARIANCE    STD DEV

(1)          10   27.099     83.672      9.1473
(2)           2   52.388     335.14      18.307
(3)          11   10.216     6.2386      2.4977
(11)         18   14.727     6.3840      2.5267

GRAND        41   18.371     132.65      11.517

Univariate 1-way ANOVA  CASES=RPT:4

ANALYSIS OF VARIANCE OF 27 BTKCY  N= 40 OUT OF 41

SOURCE              DF  SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF
```

BETWEEN	3	3040.8	1013.6	.95862	.4228
WITHIN	36	38064.	1057.3		
TOTAL	39	41105.	(RANDOM EFFECTS STATISTICS)		

ETA= .2720 ETA-SQR= .0740 (VAR COMP= -4.8975 %VAR AMONG= -0.)

EQUALITY OF VARIANCES: DF= 3, 257.85 F= 1.9666 .1194

DRG	N	MEAN	VARIANCE	STD DEV
(1)	10	56.171	1035.4	32.177
(2)	2	31.678	13.799	3.7147
(3)	10	38.410	463.68	21.533
(11)	18	56.023	1444.7	38.009
GRAND	40	50.439	1054.0	32.465

HOPPER DREDGES

```
<ANOVA OPTIONS=EQUALITY VAR=18,19,25 CASES=V2:5 STRAT=V1>

Univariate 1-way ANOVA  CASES=RPT:5

ANALYSIS OF VARIANCE OF 18.BTUPH  N= 10 OUT OF 10

SOURCE            DF SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF

BETWEEN            1    1530.3     1530.3    209.45     .0000
WITHIN             8    58.449     7.3062
TOTAL              9    1588.7     (RANDOM EFFECTS STATISTICS)

ETA= .9814  ETA-SQR= .9632  (VAR COMP= 317.28  %VAR AMONG= 97.75)

EQUALITY OF VARIANCES:  DF= 1, 161.93      F= 2.7633     .0984

DRG          N    MEAN     VARIANCE   STD DEV

(8)          6  7.4143     2.5246     1.5889
(9)          4  32.665     15.275     3.9084

GRAND       10  17.515     176.52     13.286

Univariate 1-way ANOVA  CASES=RPT:5

ANALYSIS OF VARIANCE OF 19.BTUPEH  N= 10 OUT OF 10

SOURCE            DF SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF

BETWEEN            1    3434.3     3434.3    20.736     .0019
WITHIN             8    1324.9     165.62
TOTAL              9    4759.2     (RANDOM EFFECTS STATISTICS)

ETA= .8495  ETA-SQR= .7216  (VAR COMP= 680.98  %VAR AMONG= 80.44)

EQUALITY OF VARIANCES:  DF= 1, 161.93      F= 2.9537     .0876

DRG          N    MEAN     VARIANCE   STD DEV

(8)          6  19.340     54.437     7.3782
(9)          4  57.168     350.92     18.733

GRAND       10  34.471     528.80     22.996

Univariate 1-way ANOVA  CASES=RPT:5

ANALYSIS OF VARIANCE OF 25.BTKCY  N= 10 OUT OF 10

SOURCE            DF SUM OF SQRS  MEAN SQR  F-STATISTIC SIGNIF

BETWEEN            1    3456.9     3456.9    20.014     .0021
WITHIN             8    1381.8     172.73
TOTAL              9    4838.7     (RANDOM EFFECTS STATISTICS)

ETA= .8452  ETA-SQR= .7144  (VAR COMP= 684.21  %VAR AMONG= 79.84)

EQUALITY OF VARIANCES:  DF= 1, 161.93      F= 2.6755     .1038

DRG          N    MEAN     VARIANCE   STD DEV

(8)          6  17.370     61.090     7.8160
(9)          4  55.322     358.79     18.942

GRAND       10  32.551     537.64     23.187
```

CUTTERHEAD DREDGES

<ANOVA OPTIONS=EQUALITY VAR=18,19,25 CASES=V2:5 STRAT=V1>

Univariate 1-way ANOVA CASES=RPT:5

ANALYSIS OF VARIANCE OF 18.BTUPH N= 9 OUT OF 10

SOURCE	DF	SUM OF SQRS	MEAN SQR	F-STATISTIC	SIGNIF
BETWEEN	1	771.31	771.31	27.028	.0013
WITHIN	7	199.76	28.538		
TOTAL	8	971.08	(RANDOM EFFECTS STATISTICS)		

ETA= .8912 ETA-SQR= .7943 (VAR COMP= 167.12 %VAR AMONG= 85.41)

EQUALITY OF VARIANCES: DF= 1, 139.16 F= .84066 -1 .7723

DRG	N	MEAN	VARIANCE	STD DEV
(5)	5	58.906	24.390	4.9386
(6)	4	40.276	34.069	5.8369
GRAND	9	50.626	121.38	11.017

Univariate 1-way ANOVA CASES=RPT:5

ANALYSIS OF VARIANCE OF 19.BTUPEH N= 9 OUT OF 10

SOURCE	DF	SUM OF SQRS	MEAN SQR	F-STATISTIC	SIGNIF
BETWEEN	1	3310.5	3310.5	23.857	.0018
WITHIN	7	971.36	138.77		
TOTAL	8	4281.9	(RANDOM EFFECTS STATISTICS)		

ETA= .8793 ETA-SQR= .7731 (VAR COMP= 713.65 %VAR AMONG= 83.72)

EQUALITY OF VARIANCES: DF= 1, 139.16 F= .29959 .5850

DRG	N	MEAN	VARIANCE	STD DEV
(5)	5	100.52	174.47	13.209
(6)	4	61.922	91.164	9.5480
GRAND	9	83.365	535.24	23.135

Univariate 1-way ANOVA CASES=RPT:5

ANALYSIS OF VARIANCE OF 25.BTKCY N= 9 OUT OF 10

SOURCE	DF	SUM OF SQRS	MEAN SQR	F-STATISTIC	SIGNIF
BETWEEN	1	.40198	.40198	.23136 -1	.8834
WITHIN	7	121.62	17.375		
TOTAL	8	122.03	(RANDOM EFFECTS STATISTICS)		

ETA= .0574 ETA-SQR= .0033 (VAR COMP= -3.8189 %VAR AMONG= -0.)

EQUALITY OF VARIANCES: DF= 1, 139.16 F= .54141 -1 .8164

DRG	N	MEAN	VARIANCE	STD DEV
(5)	5	30.162	15.349	3.9178
(6)	4	30.587	20.076	4.4806
GRAND	9	30.351	15.253	3.9055

DUSTPAN DREDGES

Hopper Regression Analysis Output

```
<REG BYST OPTIONS=STANDARD VAR=SAME CASES=SAME STRAT=SAME>

Least Squares Regression  <1> DRG:1  CASES=RPT:4

ANALYSIS OF VARIANCE OF 15.MBTU  N= 10 OUT OF 10

     SOURCE               DF   SUM SQRS     MEAN SQR     F-STAT     SIGNIF

     REGRESSION            7   .96472       .13782       7.8130      .1181
     ERROR                 2   .35279 -1    .17640 -1
     TOTAL                 9   1.0000

     MULT R= .98220  R-SQR= .96472  SE= .13281

     VARIABLE       PARTIAL    BETA WT    STD ERROR    T-STAT     SIGNIF

   5.VR              .79238     .54532     .29686      1.8370      .2076
   6.DRE             .84600    2.5867     1.1528       2.2439      .1540
   7.LDS           -.91854    -1.1941      .36340     -3.2860      .0815
   8.TFD             .94883     .72313     .17018      4.2493      .0512
   9.DT              .39450     .11210     .18463      .60715      .6055
  23.ANT           -.68503    -1.2371      .93028     -1.3298      .3150
  29.PTT             .79238     .38238     .20816      1.8370      .2076

Least Squares Regression  <2> DRG:2  CASES=RPT:4

VARIANCE-COVARIANCE MATRIX SINGULAR       N= 2

Least Squares Regression  <3> DRG:3  CASES=RPT:4

ANALYSIS OF VARIANCE OF 15.MBTU  N= 9 OUT OF 11

     SOURCE               DF   SUM SQRS     MEAN SQR     F-STAT     SIGNIF

     REGRESSION            7   .99451       .14207       25.867      .1503
     ERROR                 1   .54925 -2    .54925 -2
     TOTAL                 8   1.0000

     MULT R= .99725  R-SQR= .99451 SE= .74111 -1

     VARIABLE       PARTIAL    BETA WT    STD ERROR    T-STAT     SIGNIF

   5.VR            -.61102    -.11230      14549      -.77187      .5815
   6.DRE           -.34312    -.51720     1.4158      -.36530      .7770
   7.LDS             .18670     .26020     1.3692       .19004      .8804
   8.TFD           -.64711    -.34503      .40651     -.84877      .5520
   9.DT            -.83710    -.43564      28469      -1.5302      .3685
  23.ANT             30747     .51654 -1   15986       .32312      .8010
  29.PTT             .90883    1.8827      .86420      2.1786      .2740

Least Squares Regression  <11> DRG:11  CASES=RPT:4
```

ANALYSIS OF VARIANCE OF 15.MBTU N= 18 OUT OF 18

SOURCE	DF	SUM SQRS	MEAN SQR	F STAT	SIGNIF
REGRESSION	7	.98876	.14125	125.67	.0000
ERROR	10	.11240 -1	.11240 -2		
TOTAL	17	1.0000			

MULT R= .99436 R-SQR= .98876 SE= .33527 -1

VARIABLE	PARTIAL	BETA WT	STD ERROR	T-STAT	SIGNIF
5.VR	.10280	.13270 -1	.40604 -1	.32681	.7506
6.DRE	-.27928	-.26022	.28292	-.91976	.3793
7.LDS	.48781	.67435	.38161	1.7671	.1077
8.TFD	.91550	.48490	.67386 -1	7.1958	.0000
9.DT	.00699	.43226 -2	.19552	.22108 -1	.9828
23.ANT	.00540	.12556 -2	.73473 -1	.17089 -1	.9867
29.PTT	.31759	.13896	.13119	1.0592	.3144

<SEL BYST OPTIONS=FORWARD,STANDARD VAR=15,5-9,23,29 MAXIM=6 CASES=V3:4
STRAT=V1 LEVELS=.05,.1>

Selection of Regression <1> DRG:1 CASES=RPT:4

ANALYSIS AT STEP 1 FOR 15.MBTU N= 10 OUT OF 10

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	1	.46130	.46130	6.8507	.0308
ERROR	8	.53870	.67337 -1		
TOTAL	9	1.0000			

MULTIPLE R= .67919 R-SQR= .46130 SE= .25949

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
23.ANT	.67919	.67919	.25949	2.6174	.0308

REMAINING	PARTIAL	SIGNIF
5.VR	.37082	.3259
6.DRE	-.36083	.3401
7.LDS	-.40138	.2843
8.TFD	.58818	.0957
9.DT	.28924	.4503
29.PTT	-.00890	.9819

REGRESSION OF 15.MBTU USING FORWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
1	.46130	.25949	1	23.ANT	IN	.67919	.0308

Selection of Regression <2> DRG:2 CASES=RPT:4

ERROR DF=0 WITH INCLUSION OF 9.DT

Selection of Regression <3> DRG:3 CASES=RPT:4

ANALYSIS AT STEP 2 FOR 15.MBTU N= 9 OUT OF 11

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	2	.98457	.49228	191.38	.0000
ERROR	6	.15434 -1	.25723 -2		
TOTAL	8	1.0000			

MULTIPLE R= .99225 R-SQR= .98457 SE= .50718 -1

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
9.DT	-.78221	-.29183	.94892 -1	-3.0754	.0218
29.PTT	.98251	1.2266	.94892 -1	12.926	.0000

REMAINING	PARTIAL	SIGNIF
5.VR	.15844	.7344
6.DRE	-.36535	.4203
7.LDS	-.00688	.9883
8.TFD	-.45285	.3076
23.ANT	.58802	.1650

REGRESSION OF 15.MBTU USING FORWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
1	.96024	.75368 -1	1	29.PTT	IN	.97992	.0000
2	.98457	.50718 -1	2	9.DT	IN	-.78221	0218

Selection of Regression <11> DRG:11 CASES=RPT:4

ANALYSIS AT STEP 3 FOR 15.MBTU N= 18 OUT OF 18

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	3	.98727	.32909	362.03	.0000
ERROR	14	.12726 -1	.90901 -3		
TOTAL	17	1.0000			

MULTIPLE R= .99362 R-SQR= .98727 SE= .30150 -1

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
7.LDS	.59658	.32244	.11593	2.7814	.0147
8.TFD	.92793	.51431	.55216 -1	9.3145	.0000
29.PTT	.50465	.21463	.98133 -1	2.1872	.0462

REMAINING	PARTIAL	SIGNIF
5.VR	.17224	.5393
6.DRE	-.32588	.2359
9.DT	-.08061	.7752
23.ANT	.09508	.7361

REGRESSION OF 15.MBTU USING FORWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
1	.90833	.75691 -1	1	7.LDS	IN	.95307	.0000
2	98293	33739 -1	2	8.TFD	IN	.90207	.0000
3	98727	.30150 -1	3	29.PTT	IN	.50465	.0462

<SEL BYSI OPTIONS=BACKWARD,STANDARD VAR=15,5-9,23,29 MAXIM=6 CASES=V3:4
STRAT=V1 LEVELS= 05, 1>

Selection of Regression <1> DRG:1 CASES=RPT:4

ANALYSIS AT STEP 4 FOR 15.MBTU N= 10 OUT OF 10

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	3	.75782	.25261	6.2583	.0281
ERROR	6	.24218	.40363 -1		
TOTAL	9	1.0000			

MULTIPLE R= .87053 R-SQR= .75782 SE= .20091

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
5.VR	.65708	.43901	.20561	2.1351	.0767
6.DRE	.75741	.58638	.20637	2.8414	.0295
8.TFD	.73210	.53575	.20351	2.6325	.0389

REMAINING	PARTIAL	SIGNIF
7.LDS	-.62944	.1299
9.DT	.12584	.7881
23.ANT	.05592	.9052
29.PTT	.15239	.7443

REGRESSION OF 15.MBTU USING BACKWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
0	.96472	.13281	7		IN		
1	.95822	.11801	6	9.DT	OUT	.39450	.6055
2	.90808	.15159	5	23.ANT	OUT	-.73856	.1540
3	.85377	.17101	4	29.PTT	OUT	.60941	.1990
4	.75782	.20091	3	7.LDS	OUT	-.62944	.1299

Selection of Regression <2> DRG:2 CASES=RPT:4

TOO FEW CASES FOR ANALYSIS

Selection of Regression <3> DRG:3 CASES=RPT:4

ANALYSIS AT STEP 5 FOR 15.MBTU N= 9 OUT OF 11

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	2	.98457	.49228	191.38	.0000
ERROR	6	.15434 -1	.25723 -2		
TOTAL	8	1.0000			

MULTIPLE R= .99225 R-SQR= .98457 SE= .50718 -1

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
9.DT	-.78221	-.29183	.94892 -1	-3.0754	.0218
29.PTT	.98251	1.2266	.94892 -1	12.926	.0000

REMAINING	PARTIAL	SIGNIF
5.VR	.15844	.7344
6.DRE	-.36535	.4203
7.LDS	-.00688	.9883
8.TFD	-.45285	.3076
23.ANT	.58802	.1650

REGRESSION OF 15.MBTU USING BACKWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
0	.99451	.74111 -1	7		IN		
1	.99431	.53343 -1	6	7.LDS	OUT	.18670	.8804
2	.99334	.47117 -1	5	6.DRE	OUT	-.38146	.6185
3	.99117	.46992 -1	4	5.VR	OUT	-.49599	.3954
4	.98990	.44939 -1	3	8.TFD	OUT	-.35388	.4913
5	.98457	.50718 -1	2	23.ANT	OUT	.58802	.1650

Selection of Regression <11> DRG:11 CASES=RPT:4

ANALYSIS AT STEP 4 FOR 15.MBTU N= 18 OUT OF 18

SOURCE	DF	SUM OF SQRS	MEAN SQUARE	F-STAT	SIGNIF
REGRESSION	3	.98727	.32909	362.03	.0000
ERROR	14	.12726 -1	.90901 -3		
TOTAL	17	1.0000			

MULTIPLE R= .99362 R-SQR= .98727 SE= .30150 -1

VARIABLE	PARTIAL	BETA WEIGHT	STD ERROR	T-STAT	SIGNIF
7.LDS	.59658	.32244	.11593	2.7814	.0147
8.TFD	.92793	.51431	.55216 -1	9.3145	.0000
29.PTT	.50465	.21463	.98133 -1	2.1872	.0462

REMAINING	PARTIAL	SIGNIF
5.VR	.17224	.5393
6.DRE	-.32588	.2359
9.DT	-.08061	.7752
23.ANT	.09508	.7361

REGRESSION OF 15.MBTU USING BACKWARD SELECTION

STEP	R-SQR	STD ERROR	# VAR	VARIABLE		PARTIAL	SIGNIF
0	98876	33527 -1	7		IN		
1	98876	31967 -1	6	23.ANT	OUT	.00540	.9867
2	98876	30607 -1	5	9.DT	OUT	.00909	.9765
3	98863	.29580 -1	4	5.VR	OUT	.10816	.7128
4	98727	30150 -1	3	6.DRE	OUT	-.32588	.2359

Correlation Analysis Output

<CORR BYST VAR=5-13,15,23,29 CASES=V3:4 STRAT=V1>

Correlation Matrix <1> DRG:1 CASES=RPT:4

N= 10 DF= 8 R@ 0500= 6319 R@ 0100= .7646

VARIABLE	5 VR	6 DRE	7 LDS	8 TFD	9 DT	10 ET	11 LT	12 RT	13 NT	15 MBTU	23 ANT	29 PTT
5 VR	1 0000											
6 DRE	-.1967	1 0000										
7 LDS	-.1024	.8566	1 0000									
8 TFD	-.1073	.1368	.0481	1.0000								
9 DT	.4721	2640	.3576	-.0349	1.0000							
10 ET	.0312	.3205	.2848	.9301	.1557	1.0000						
11 LT	-.0332	.2850	.1127	.9359	.0854	.9470	1.0000					
12 RT	0175	.5561	.4534	.8514	2091	.9596	.9264	1.0000				
13 NT	-.0167	.8983	.6830	.4441	.2621	.6033	.6210	.8032	1 0000			
15 MBTU	.2662	.5733	.3259	.5689	.3931	.7222	.7184	.8146	7798	1.0000		
23 ANT	-.0088	9571	.7612	.2171	.2786	.3994	.4031	.6395	.9676	6792	1.0000	
29 PTT	.3169	.4505	.5932	-.3130	3594	.0531	-.0999	.1608	.3442	.2889	.4341	1 0000

Correlation Matrix <2> DRG:2 CASES=RPT:4

TOO FEW CASES FOR ANALYSIS

Correlation Matrix <3> DRG 3 CASES=RPT 4

N= 9 DF= 7 R@ 0500= 6664 R@ 0100= 7977

VARIABLE	5 VR	6 DRE	7 LDS	8 TFD	9 DT	10 ET	11 LT	12 RT	13 NT	15 MBTU	23 ANT	29 PTT
5 VR	1 0000											
6 DRE	- 0978	1 0000										
7 LDS	- 0453	9940	1 0000									
8 TFD	3859	8755	8619	1 0000								
9 DT	2583	8537	8692	5457	1 0000							
10 ET	2405	9532	9462	9773	7030	1.0000						
11 LT	1437	9344	9459	8987	.7370	.9471	1 0000					
12 RT	1501	9363	9504	9297	.7240	9696	9907	1 0000				
13 NT	0619	.8199	8628	7499	7114	.8199	9377	9296	1 0000			
15 MBTU	1104	9560	9601	9162	7448	9702	9747	9834	8897	1 0000		
23 ANT	4148	3346	4202	2256	4245	3113	5076	5043	7752	4344	1 0000	
29 PTT	0419	9881	9896	8883	8452	.9653	9487	9594	8573	9799	4014	1 0000

HOPPER DREDGES

Correlation Matrix <11> DRG 11 CASES=RPT 4

N= 18 DF= 16 R@ .0500= .4683 R@ .0100= .5897

VARIABLE	5. VR	6. DRE	7. LDS	8. TFD	9. DT	10. ET	11 LT	12. RT	13 NT	15 MBTU	23 ANT	29 PTT
5 VR	1.0000											
6 DRE	.3456	1.0000										
7 LDS	-.2952	.9878	1.0000									
8 TFD	-.2279	.7956	.8299	1.0000								
9. DT	-.2964	.9798	.9807	.7923	1.0000							
10. ET	-.2416	.9487	.9738	.9174	.9558	1.0000						
11 LT	-.2179	.9057	.9472	.8733	.9206	.9561	1.0000					
12 RT	-.2323	.9481	.9771	.9082	.9589	.9963	.9742	1.0000				
13 NT	-.2029	.9181	.9557	.8586	.9375	.9576	.9885	.9787	1.0000			
15 MBTU	-.2306	.9201	.9531	.9433	.9207	.9877	.9687	.9888	.9617	1.0000		
23 ANT	-.1374	.8411	.8635	.7148	.8703	.8459	.8375	.8726	.9106	.8266	1.0000	
29 PTT	-.1640	.9191	.9495	.7521	.9259	.9428	.9002	.9406	.9070	.9076	.8160	1.0000

HOPPER DREDGES

<CORR BYST VAR=5-9,11,12,13,14 CASES=V2:5 STRAT=V1 LEVELS=.05,.1>

Correlation Matrix <8> DRG:8 CASES=RPT:5

N= 4 DF= 2 R@ .0500= .9500 R@ .1000= .9000

VARIABLE	5. ADV	6. PL	7. DPH	8. ET	9. NT	11. MBTU	12. TOT	13. APH	14. DRE
5.ADV	1.0000								
6.PL	-.5901	1.0000							
7.DPH	.0199	.7415	1.0000						
8.ET	.5176	-.1523	.4873	1.0000					
9.NT	-.7930	.4295	-.2785	-.9262	1.0000				
11.MBTU	.0584	-.2814	-.6258	-.8206	.5454	1.0000			
12.TOT	-.0702	.3267	.6637	.8090	-.5277	-.9986	1.0000		
13.APH	.6296	-.4578	-.3639	-.3364	-.0268	.8007	-.7998	1.0000	
14.DRE	.7886	-.4105	.2987	.9310	-.9998	-.5555	.5388	.0189	1.0000

Correlation Matrix <9> DRG:9 CASES=RPT:5

N= 4 DF= 2 R@ .0500= .9500 R@ .1000= .9000

VARIABLE	5. ADV	6. PL	7. DPH	8. ET	9. NT	11. MBTU	12. TOT	13. APH	14. DRE
5.ADV	1.0000								
6.PL	-.7650	1.0000							
7.DPH	.8901	-.3910	1.0000						
8.ET	.7828	-.9907	.4136	1.0000					
9.NT	-.5806	.9424	-.1506	-.9583	1.0000				
11.MBTU	.8878	-.5530	.9080	.5214	-.2583	1.0000			
12.TOT	.6804	-.1396	.9025	.1163	.1723	.9001	1.0000		
13.APH	.5974	.0452	.8960	-.0313	.3039	.7613	.9488	1.0000	
14.DRE	.8906	-.9651	.5864	.9800	-.8866	.6573	.2965	.1672	1.0000

<MCORR BYST VAR=SAME CASES=SAME STRAT=V1:8>

Missing Data Correlation <1> DRG:8 CASES=RPT:5

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
5.ADV 6.PL	10330. 2784.8	3809.1 1240.4	4	-.5901	-1.0336	.4099
5.ADV 7.DPH	10330. 789.00	3809.1 196.81	4	.0199	.28094 -1	.9801
5.ADV 8.ET	10330. 233.36	3809.1 67.042	4	.5176	.85561	.4824
5.ADV 9.NT	10330. 299.00	3809.1 46.397	4	-.7930	-1.8408	.2070
5.ADV 11.MBTU	10330. 3617.7	3809.1 525.10	4	.0584	.82778 -1	.9416
5.ADV 12.TOT	10330. 532.36	3809.1 29.752	4	-.0702	-.99535 -1	.9298
5.ADV 13.APH	10330. 45.137	3809.1 12.015	4	.6296	1.1461	.3704
5.ADV 14.DRE	10330. .25448 +6	3809.1 97986.	4	.7886	1.8134	.2114
6.PL 7.DPH	2784.8 789.00	1240.4 196.81	4	.7415	1.5628	.2585
6.PL 8.ET	2784.8 233.36	1240.4 67.042	4	-.1523	-.21790	.8477
6.PL 9.NT	2784.8 299.00	1240.4 46.397	4	.4295	.67268	5705
6.PL 11.MBTU	2784.8 3617.7	1240.4 525.10	4	-.2814	-.41468	.7186
6.PL 12.TOT	2784.8 532.36	1240.4 29.752	4	.3267	.48885	.6733
6.PL 13.APH	2784.8 45.137	1240.4 12.015	4	-.4578	-.72814	.5422
6.PL 14.DRE	2784.8 .25448 +6	1240.4 97986.	4	-.4105	-.63671	.5895
7.DPH 8.ET	789.00 233.36	196.81 67.042	4	.4873	.78908	.5127
7.DPH 9.NT	789.00 299.00	196.81 46.397	4	-.2785	-.41006	.7215
7.DPH 11.MBTU	789.00 3617.7	196.81 525.10	4	-.6258	-1.1348	.3742

CUTTERHEAD DREDGES

7.DPH	789.00	196.81	4	.6637	1.2548		.3363
12.TOT	532.36	29.752					
7.DPH	789.00	196.81	4	-.3639	-.55248		.6361
13.APH	45.137	12.015					
7.DPH	789.00	196.81	4	.2987	.44265		.7013
14.DRE	.25448 +6	97986.					
8.ET	225.41	60.046	6	-.3382	-.71882		.5120
9.NT	321.50	60.428					
8.ET	225.41	60.046	6	-.5459	-1.3030		.2625
11.MBTU	4008.2	729.70					
8.ET	225.41	60.046	6	.5715	1.3930		.2360
12.TOT	546.91	69.300					
8.ET	233.36	67.042	4	-.3364	-.50514		.6636
13.APH	45.137	12.015					
8.ET	225.41	60.046	6	.8735	3.5881		.0230
14.DRE	.25811 +6	78306.					
9.NT	321.50	60.428	6	.6833	1.8718		.1346
11.MBTU	4008.2	729.70					
9.NT	321.50	60.428	6	.5789	1.4199		.2286
12.TOT	546.91	69.300					
9.NT	299.00	46.397	4	-.0268	-.37946	-1	.9732
13.APH	45.137	12.015					
9.NT	321.50	60.428	6	-.4031	-.88102		.4281
14.DRE	.25811 +6	78306.					
11.MBTU	4008.2	729.70	6	.1229	.24758		.8166
12.TOT	546.91	69.300					
11.MBTU	3617.7	525.10	4	.8007	1.8905		.1993
13.APH	45.137	12.015					
11.MBTU	4008.2	729.70	6	-.2303	-.47339		.6606
14.DRE	.25811 +6	78306.					
12.TOT	532.36	29.752	4	-.7998	-1.8844		.2002
13.APH	45.137	12.015					
12.TOT	546.91	69.300	6	.4053	.88673		.4253
14.DRE	.25811 +6	78306.					
13.APH	45.137	12.015	4	.0189	.26714	-1	.9811
14.DRE	.25448 +6	97986.					

<CORR BYST VAR=5-9,11,12,14,22 CASES=V2:5 STRAT=V1 LEVELS=.05,.1>

Correlation Matrix <5> DRG:5 CASES=RPT:5

N= 5 DF= 3 R@ .0500= .8783 R@ .1000= .8054

VARIABLE	5. ADV	6. PL	7. DPH	8. ET	9. NT	11. MBTU	12. TOT	14. DRE	22. DEP
5.ADV	1.0000								
6.PL	-.2570	1.0000							
7.DPH	.4955	.1807	1.0000						
8.ET	.8372	-.5436	.3845	1.0000					
9.NT	-.2084	.7422	.4569	-.5973	1.0000				
11.MBTU	.9643	-.2068	.6287	.8922	-.2056	1.0000			
12.TOT	.6975	.2253	.9378	.4438	.4536	.7617	1.0000		
14.DRE	.8445	-.5187	.4271	.9989	-.5619	.9062	.4822	1.0000	
22.DEP	-.6633	-.4022	-.4140	-.1584	-.4629	-.5557	-.6932	-.1764	1.0000

Correlation Matrix <6> DRG:6 CASES=RPT:5

N= 4 DF= 2 R@ .0500= .9500 R@ .1000= .9000

VARIABLE	5. ADV	6. PL	7. DPH	8. ET	9. NT	11. MBTU	12. TOT	14. DRE	22. DEP
5.ADV	1.0000								
6.PL	-0.	-0.							
7.DPH	-.4190	-0.	1.0000						
8.ET	.9075	-0.	-.6659	1.0000					
9.NT	-.9402	-0.	.6981	-.9759	1.0000				
11.MBTU	.1178	-0.	-.0848	.3953	-.1855	1.0000			
12.TOT	.4981	-0.	-.3398	.7354	-.5699	.9127	1.0000		
14.DRE	.9448	-0.	-.4376	.9622	-.9238	.4350	.7546	1.0000	
22.DEP	-.9851	-0.	.5136	-.8925	.9552	.0096	-.3947	-.8933	1.0000

DUSTPAN DREDGES

<WRITE VAR=1-18,23,25,26,27,29 CASES=V3 4>

Write Observations CASES=RPT:4
VARIABLES BY CASE

1 ORG	2 CAP	3 RPT	4 DAT	5 VR	6 DRE	7 LDS	8 TFD	9 DT	10 ET	11 LT	12 RT
13 NT	14 BBL	15 MBTU	16 BTUPEH	17 BTUPH	18 DPBT	23 ANT	25 BTUPT	26 BTUCY	27 BTKCY	29 PTT	
1	3140.0	4	5081	1445	.50952 +6	349.00	973.00	29.000	1111.0	97.000	1378.0
267.00	2636.0	15500.	13.951	11.248	32.873	170.00	12.100	.30420 -1	30.420	109.00	
1	3140.0	4	7091	1670	.59684 +6	320.00	67.000	44.000	614.00	45.000	904.00
290.00	3872.0	22767.	37.080	25.185	26.215	245.00	26.504	.38146 -1	38.146	503.00	
1	3140.0	4	8171	1453	.49078 +6	204.00	297.00	29.000	516.00	28.000	671.00
154.00	4603.0	27066.	52.453	40.336	18.133	126.00	42.158	.55148 -1	55.148	190.00	
1	3140.0	4	5229	1981	.40662 +6	241.00	265.00	95.000	582.00	40.000	804.00
221.00	5176.0	30435.	52.294	37.854	13.360	181.00	39.888	.74849 -1	74.849	222.00	
1	3140.0	4	7059	1981	.31770 +6	272.00	244.00	23.000	612.00	15.000	761.00
149.00	3859.0	22691.	37.077	29.817	14.001	134.00	30.417	.71423 -1	71.423	345.00	
1	3140.0	4	12169	1642	48048.	17.000	12.000	1.0000	33.000	0.	57.000
23.000	129.00	758.52	22.985	13.307	63.344	23.000	13.545	.15787 -1	15.787	20.000	
1	3140.0	4	1030	1650	.13090 +7	476.00	530.00	41.000	880.00	87.000	1577.0
697.00	7787.0	45788.	52.031	29.035	28.588	610.00	30.730	.34980 -1	34.980	309.00	
1	3140.0	4	5180	1728	.39587 +6	141.00	1005.0	28.000	1189.0	133.00	1503.0
314.00	6901.0	40578.	34.128	26.998	9.7559	181.00	29.619	.10250	102.50	156.00	
1	3140.0	4	5180	1728	.39585 +6	141.00	1005.0	28.000	1189.0	132.00	1554.0
365.00	7345.0	43189.	36.323	27.792	9.1655	233.00	30.372	.10910	109.10	156.00	
1	3140.0	4	8140	1480	.54429 +6	272.00	149.00	23.000	353.00	12.000	543.00
190.00	2717.0	15976.	45.258	29.422	34.069	178.00	30.087	.29352 -1	29.352	181.00	
2	7872.0	4	10012	1450	.53135 +6	14.000	7.0000	.90000	160.50	2.4100	279.00
118.33	3100.0	18228.	113.57	65.333	29.150	115.92	65.943	.34305 -1	34.305	152.60	
2	7828.0	4	3303	1573	.90695 +6	235.00	107.50	28.660	342.66	0.	668.00
325.33	4481.0	26348.	76.893	39.444	34.422	325.33	39.444	.29052 -1	29.052	206.50	
3	825.00	4	1072	2011	.24413 +6	340.00	173.95	14.330	356.97	199.00	684.41
327.50	1293.0	7602.8	21.298	11.109	32.110	128.50	15.661	.31143 -1	31.143	168.69	
3	825.00	4	6152	1930	.32875 +6	440.00	182.90	23.500	394.90	272.00	781.90
387.00	1288.0	7573.4	19.178	9.6859	43.408	115.00	14.853	.23037 -1	23.037	188.50	
3	825.00	4	6182	2063	.19339 +6	302.00	73.830	22.500	229.50	154.00	527.66
298.00	824.00	4845.1	21.112	9.1823	39.914	144.00	12.972	.25054 -1	25.054	133.17	
3	825.00	4	9082	1995	81190.	107.00	64.660	9.3300	148.33	72.000	239.00
90.660	502.00	2951.8	19.900	12.350	27.506	18.660	17.676	.36356 -1	36.356	74.340	
3	825.00	4	11052	1476	5775.0	7.0000	7.7500	.50000	13.660	0.	16.000
2.3300	43.000	252.84	18.510	15.802	22.841	2.3300	15.812	.43782 -1	43.782	5.4100	

HOPPER DREDGES

3	825 00	4	9262	0	27300.	36.000	14 000	3 0000	58 500	0	72 500
13 900	152 00	893 76	15.278	12.328	30 545	13 900	12 345	32738 -1	32 738	41 500	
3	825 00	4	9292	1709	-0	-0	0	0.	0	12 000	29 500
29 500	48 000	282 24	-0.	9 5675	-0.	17 500	16 128	-0	-0	0.	
3	825 00	4	6132	2038	31395.	75.000	17.200	3.3300	51.200	27.000	139 66
88 500	194 00	1140.7	22.280	8.1678	27.522	61 500	10.122	36334 -1	36 334	30.670	
3	825 00	4	8122	2072	50905.	95.000	27 500	8.6600	87.000	49.000	205 40
188.33	250.00	1470.0	16.897	7.1568	34.629	139.33	6.4949	.28877 -1	28.877	50.840	
3	825.00	4	4082	1961	34030.	93.000	30.500	4.4000	85.000	139.00	405 00
320.20	563.00	3310.4	38.946	8.1739	10.280	181.20	12.436	.97280 -1	97.280	50.100	
3	825.00	4	4202	1534	.31319 +6	431.00	362.00	14.330	580.00	312.00	1044.0
426.80	1571.0	9237.5	15.927	8.8482	33.904	114.80	13.295	.29495 -1	29.495	203.67	
11	2790.0	4	9100	1350	.13179 +6	99.000	288.00	36.000	403.00	72.000	503 00
100.00	1554.0	9137.5	22.674	18.166	14.423	28.000	21.201	.69336 -1	69.336	79.000	
11	2790.0	4	10061	1423	.56583 +6	512.00	444.00	332.00	1243.0	384.00	1747 0
504.00	4052.0	23826.	19.168	13.638	23.749	120.00	17.480	42108 -1	42.108	467.00	
11	2790.0	4	3231	1450	.39643 +6	289.00	428.00	159.00	833.00	144.00	1053.0
220.00	2769.0	16282.	19.546	15.462	24.348	76.000	17.912	.41071 -1	41.071	246.00	
11	2790.0	4	5061	1524	.42541 +6	389.00	250.00	205.00	856.00	216.00	1176.0
320.00	2830.0	16640.	19.440	14.150	25.565	104.00	17.334	.39116 -1	39.116	401.00	
11	2790.0	4	6241	1222	.55959 +6	416.00	369.00	298.00	872.00	216.00	1170 0
298 00	2878.0	16923.	19.407	14.464	33.067	82.000	17.739	.30241 -1	30.241	205.00	
11	2790.0	4	10010	1320	.12001 +6	81.000	75.000	50.000	190.00	72 000	290 00
100.00	750.00	4410.0	23.211	15.207	27.213	28.000	20.229	.36747 -1	36.747	65.000	
11	2790.0	4	10150	1507	.29537 +6	181.00	69.000	131.00	363.00	72.000	479.00
116.00	1276.0	7502.9	20.669	15.664	39.368	44.000	18.435	25402 -1	25.402	163.00	
11	2790.0	4	11040	1450	.10278 +6	75.000	96.000	50.000	202.00	8.0000	315.00
113.00	835.00	4909.8	24.306	15.587	20.934	105.00	15.993	.47768 -1	47.768	56.000	
11	2790.0	4	12180	1320	3786.0	3.0000	16.000	3.0000	22.000	24.000	93.000
71.000	100.00	588.00	26.727	6.3226	6.4388	47 000	8.5217	.15531	155.31	3.0000	
11	2790.0	4	7090	1698	76125.	58.000	267.00	52.000	388.00	77.000	514 00
126.00	1369.0	8049.7	20.747	15.661	9.4569	49.000	18.420	.10574	105.74	69.000	
11	2790.0	4	10099	1699	38839.	25.000	120.00	33.000	183.00	60.000	307.00
124.00	793.00	4662.8	25.480	15.188	8.3295	64.000	18.878	.12006	120.06	30.000	
11	2790.0	4	9059	1431	.69835 +6	593.00	632.00	315.00	1313.0	472.00	1942 0
629.00	5157.0	30323.	23.095	15.614	23.030	157.00	20 628	.43421 -1	43.421	366 00	
11	2790.0	4	7310	1257	.32991 +6	190.00	91.000	110.00	368.00	72.000	477.00
109.00	1214.0	7138.3	19.398	14.965	46.216	37.000	17.625	.21637 -1	21.637	167.00	
11	2790 0	4	9100	1350	.12761 +6	96.000	282.00	35.000	395.00	72.000	493 00
98.000	1526.0	8972.9	22.716	18.201	14.221	26.000	21.313	.70318 -1	70.318	78.000	

HOPPER DREDGES

11	2790.0	4	4070	1518	.14128 +6	110.00	64.000	11.000	140.00	24.000	184.00
44.000	471.00	2769.5	19.782	15.052	51.013	20.000	17.309	.19603 -1	19.603	65.000	
11	2790.0	4	8190	1320	.24206 +6	156.00	118.00	98.000	333.00	120.00	518.00
185.00	1174.0	6903.1	20.730	13.326	35.065	65.000	17.345	.28519 -1	28.519	117.00	
11	2790.0	4	4150	1384	.91730 +6	702.00	492.00	457.00	1446.0	384.00	2040.0
594.00	4355.0	25607.	17.709	12.553	35.821	210.00	15.463	.27916 -1	27.916	497.00	
11	2790.0	4	3252	1970	29435.	22.000	20.000	8.0000	104.00	24.000	156.00
52.000	421.00	2475.5	23.803	15.868	11.891	28.000	18.754	.84100 -1	84.100	76.000	

HOPPER DREDGES

<WRITE VAR=1-15,18,19,22,25 CASES=V2:5>

Write Observations CASES=RPT:5
VARIABLES BY CASE

1. DRG	2. RPT	3. DAT	4. VR	5. ADV	6. PL	7. DPH	8. ET	9. NT	10. OIL	11. MBTU	12. TOT
13. APH	14. DRE	15. DPBT	18. BTUPH	19. BTUPEH	22. DEP	25. BTKCY					
5	5	4192	9815	.10800 +6	850.00	3293.0	386.16	188.08	5346.0	34802.	574.24
279.68	.12716 +7	36.538	60.606	90.124	9.0830	27.368					
5	5	5132	9815	.22250 +6	875.00	3378.0	536.00	232.50	7361.0	47920.	768.50
415.11	.18106 +7	37.784	62.355	89.403	6.2775	26.466					
5	5	7012	9815	.14560 +6	900.00	3286.0	342.16	282.83	5720.0	37237.	624.99
425.53	.11243 +7	30.194	59.580	108.83	5.9570	33.119					
5	5	9012	9815	.22590 +6	850.00	3334.0	469.33	250.66	6825.0	44431.	719.99
481.32	.15647 +7	35.218	61.710	94.668	5.3435	28.395					
5	5	8012	9815	.13280 +6	900.00	3372.0	312.84	431.16	5746.0	37406.	744.00
424.50	.10549 +7	28.201	50.277	119.57	6.1278	35.460					
6	5	8011	0	14400.	800.00	2489.0	39.160	16.330	-0.	-0.	55.490
367.72	97469.	-0.	-0.	-0.	5.2216	-0.					
6	5	9011	0	.16890 +6	800.00	1986.0	487.83	232.16	3604.0	23462.	719.99
346.23	.96883 +6	41.294	32.587	48.095	4.4250	24.217					
6	5	10011	0	.18530 +6	800.00	2058.0	512.33	229.66	4985.0	32452.	741.99
361.68	.10544 +7	32.490	43.737	63.343	4.3895	30.779					
6	5	11011	0	.10240 +6	800.00	2093.0	405.16	314.84	4320.0	28123.	720.00
252.74	.84800 +6	30.153	39.060	69.413	6.3884	33.164					
6	5	12011	0	.15100 +6	800.00	1955.0	508.91	235.09	5225.0	34015.	744.00
296.71	.99492 +6	29.250	45.719	66.838	5.0828	34.188					

DUSTPAN DREDGES

<WRITE VAR=1-15,18,19,25 CASES=V2.5>

Write Observations CASES=RPT 5
VARIABLES BY CASE

1. DRG	2 RPT	3. DAT	4. VR	5. ADV	6. PL	7. DPH	8. ET	9. NT	10. OIL	11. MBTU	12 TOT
13. APH	14. DRE	15. DPBT	18. BTUPH	19. BTUPEH	25. BTKCY						
8	5	7012	1001	7395.0	3956.0	817.00	150.84	358.00	691.00	4063.1	508.84
49.025	.13099 +6	32.239	7.9850	26.936	31.018						
8	5	8012	9514	9190.0	1534.0	524.00	208.77	311.00	647.00	3804.4	519.77
44.020	.22638 +6	59.505	7.3193	18.223	16.805						
8	5	9012	1001	15925.	1909.0	815.00	274.00	251.00	637.00	3745.6	525.00
58.120	.35552 +6	94.918	7.1344	13.670	10.535						
8	5	6012	9712	8810.0	3740.0	1000.0	299.83	276.00	486.00	2857.7	575.83
29.383	.30503 +6	106.74	4.9627	9.5310	9.3685						
8	5	10012	0	-0.	-0.	-0.	253.00	420.00	823.00	4839.2	673.00
-0.	.29451 +6	60.859	7.1905	19.127	16.431						
8	5	11012	0	-0.	-0.	-0.	166.00	313.00	806.00	4739.3	479.00
-0.	.23625 +6	49.849	9.8941	28.550	20.060						
9	5	8011	0	8110.0	1450.0	961.00	454.08	164.66	2832.0	18436.	618.74
17.860	.43637 +6	23.669	29.797	40.601	42.249						
9	5	9011	0	13375.	1376.0	1077.0	451.25	250.25	3976.0	25884.	701.50
29.640	.48600 +6	18.776	36.898	57.360	53.259						
9	5	10011	0	15200.	1315.0	1101.0	504.66	178.00	3675.0	23924.	682.66
30.119	.55563 +6	23.225	35.046	47.407	43.058						
9	5	11011	0	6300.0	2538.0	1007.0	230.15	432.75	2945.0	19172.	662.90
27.373	.23176 +6	12.089	28.921	83.302	82.723						

CUTTERHEAD DREDGES

APPENDIX B:

DREDGE ENERGY STRATEGIES

In evaluating the energy-saving technical options, each option was assigned to one of four levels of energy savings:

A = 0 to 3 percent
B = 3 to 10 percent
C = 10 to 15 percent
D = Special cases ranging between 15 and 50 percent.

When combining strategies to estimate the maximum possible savings for each dredge from all potentially applicable strategies, the midpoint of each savings range was used, e.g., A = 1.5 percent and B = 6.5 percent.

ENERGY STRATEGY 1

Major Area Engines

Strategy Title Steam to Diesel Conversion

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham		Ste. Gene.	X
McFarland		Thompson	
Yaquina			

Description

Older steam-powered ships expected to remain in the fleet over the medium to long term can be repowered economically with diesel engines. A variety of low- and medium-speed diesel engines are available. Final design selection should consider both the duty cycle requirements and the future availability of alternative fuels. For example, it is possible that low-speed diesel engines could be modified to burn some type of synthetic fuel or low concentrations of coal in coal/oil slurries. Although pulverized coal with higher slurry concentrations may be possible after further technical development, they are not practical currently and would require major redesign. The duty cycle of dredging operations appears to make the power loop concept, incorporating multiple engines, an especially attractive and efficient option.

Energy Savings Analysis

Studies have claimed efficiency (and cost) improvements in the range of 25 to 50 percent for steam-to-diesel conversions (see references). The higher end of the efficiency range is associated with the power loop concept.

Energy Savings Rating D

Major Barriers or Issues

The ship's expected life and duty requirements must be considered. Also, long-term fuel use issues related to dependence on petroleum-based fuels versus coal-based fuels must be assessed. Conversion brings significant changes to training and duties of engine room crew. Detailed engineering studies are required to document the expected level of energy savings from this type conversion. Also, see the discussion of fuel substitution in this appendix.

References

Bertram, K. M., C. L. Saricks, and E. W. Gregory II, Summary of International Maritime Fuel Conservation Measures (Center for Transportation Research, Argonne National Laboratory, 1981).

Marine Engineering Class of 1980, SUNY Maritime College, "Design of a Coal-Fired Steam Power Plant for a Containership," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Michiura, T., D. Kozai, and P. Vragel, "Re-Engining of a VLCC with Low-Speed Geared Diesel Engines," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

National Academy of Sciences, "Alternate Fuels for Maritime Use," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

St. Louis District Energy Plan, U.S. Army Corps of Engineers, St. Louis District (1982); Vicksburg District Installation Energy Plan, U.S. Army Corps of Engineers, Vicksburg District (1982).

ENERGY STRATEGY 2

Major Area Engines

Strategy Title Performance Modifications

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham	X	Ste. Gene.	X
McFarland	X	Thompson	X
Yaquina			

Description

Several technical performance modifications are available for both existing steam- and diesel-powered plants. These include approaches such as regenerative feedwater heaters, continuous monitoring of carbon monoxide or oxygen flue gas, reduced condensate cooling, and condensate cooling of lube oil. Assessment of applicability to specific ships requires a careful engineering evaluation of the existing plant and expected duty cycle.

Energy Savings Analysis

Technology-based efficiency improvements of up to 10 percent are reportedly possible, depending on existing engine condition and specific system applicability. Maintenance-based efficiency improvements, such as cleaning the boilers, can yield gains of up to 5 percent. Careful engineering-economic evaluation is required on a ship-by-ship basis. Given the quality of maintenance followed by Corps' dredge crews, it is unlikely that any single modification would provide more than a 5 percent efficiency improvement, and no combination of modifications would provide more than 10 percent.

Energy Savings Rating B

Major Barriers or Issues

The gains from many of the engine modifications are generally small. More importantly, they may be somewhat uncertain when extrapolated to new, untested system configurations and duty cycles. Some modifications may increase system complexity and the maintenance requirements. Variable loads in dredge operation may make heat recovery approaches unsuitable; however, technical advances developed for solar energy technologies may open new options for marine use, e.g., steam absorption air-conditioning.

References

Bertram, K. M., C. L. Saricks, and E. W. Gregory II, Summary of International Maritime Fuel Conservation Measures (Center for Transportation Research, Argonne National Laboratory, 1981).

Murray T., "Saving Money by Improving Efficiency," World Dredging and Marine Construction (1982).

Rein, H., "Ways to Reduce Slow Steaming Fuel Consumption of Steam Turbine Machinery Through Technical Modifications," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Sweeney, J. J., "A Comprehensive Program for Shipboard Energy Conservation," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

ENERGY STRATEGY 3

Major Area Fuels

[illegible] Fuel Substitution

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham		Ste. Gene.	X
McFarland		Thompson	
Yaquina			

Description

From a technical standpoint, several fuel substitution alternatives exist for both diesel- and steam-powered dredges. However, most diesel alternatives such as pulverized coal, coal slurry, synthetic fuels, and alcohol-based fuels are not currently practical within existing technology and economics. Many existing steam-based systems could be modified to operate on synthetic fuels and, in some cases, on coal/oil slurries. The lower energy content of many of these fuels creates storage problems for most ships; this is especially true for direct burning of coal through stoker firing, pulverizers, or atmospheric fluidized-bed combustion. These direct coal-burning systems are the most practical from a technical standpoint, but will require additional development for marine use. Nuclear-based options for marine use have been available for almost 2 decades. In theory, these could be adapted for dredges. However, this approach would require a thorough evaluation of economic, engineering, political, and environmental issues.

Energy Savings Analysis

None of the substitution options reduce overall energy consumption significantly. They can, however, greatly reduce consumption of petroleum-based fuels. In the case of coal/oil slurries, the savings could be in the range of 15 to 45 percent. Direct burning of coal could reduce petroleum use by as much as 95 percent. Perhaps even more important is the diversity of fuel use that coal-burning would introduce to the Corps' dredge fleet.

Energy Savings Rating D

Major Barriers or Issues

Most fuel substitution options involve major retrofitting or new ship design. Furthermore, they would involve the Corps and its suppliers in new, unfamiliar areas covering a full range of issues such as engine design, materials and maintenance, and fuel processing, delivery, storage, handling.

References

Albino, J. A., and J. E. Swensson, "A Prototype Steam Plant With Fluid Bed Designed for Uncertain Energy Conditions," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Bertram, K. M., C. L. Saricks, and E. W. Gregory II, Summary of International Maritime Fuel Conservation Measures (Center for Transportation Research, Argonne National Laboratory, 1981).

Horlitz, C. F., and S. E. Sabo, "Coal-Fired Boilers for the 1980's," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Marine Engineering Class of 1980, SUNY Maritime College, "Design of a Coal-Fired Steam Power Plant for a Containership," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

National Academy of Sciences, "Alternate Fuels for Maritime Use," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Schroppe, J. T., and U. Niatis, "Marine Steam Power Plant Alternatives in the Degrading Fuel Quality and Increasing Price Environment," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

Winkler, M. F., "Slurry Fuels: The Retrofittable Alternative," Presented at Shipboard Energy Conservation '80, The Society of Naval Architects and Marine Engineers, September 22-23, 1980, New York City.

ENERGY STRATEGY 4

Major Area Pumps and Pipelines

Strategy Title Submersible Pumps

Applicability

Wheeler		Jadwin	
Essayons		Potter	
Markham	X	Ste. Gene.	
McFarland	X	Thompson	
Yaquina	X		

Description

Dragarm-mounted submersible pumps have been developed over the past decade as a tool for increasing both maximum dredge depth and productivity. Submersible pumps have been incorporated into the newly built hopper dredges Wheeler and Essayons. They have also been retrofit on several older dredges. Production increases of 25 to 50 percent have been noted for retrofit systems. The time-dependence of dredge energy consumption means that increased productivity typically can be translated into increased energy efficiency. That is, a job completed in less time will also be completed with less energy.

Energy Savings Analysis

The exact relationship between increased productivity due to submersible pumps and increased energy efficiency is unclear. A suitable analysis requires data that are not currently available. A conservative estimate of maximum energy savings probably would be in the range of 3 to 10 percent.

Energy Savings Rating B

Major Barriers or Issues

Submersible pump use must be evaluated on a case-by-case basis, depending on existing plant specifications, anticipated job requirements, and engineering-economic analyses of costs and benefits. Production increases typically are smaller for shallow dredging. The added weight of outboard pumps and heavier winches can produce stability problems in retrofit applications.

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ENERGY STRATEGY 5

Major Area Pumps and Pipelines

Strategy Title Suction Relief Valves

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham		Ste. Gene.	X
McFarland		Thompson	X
Yaquina			

Description

Suction relief systems serve to increase the concentration of solids in the pumping system and simultaneously reduce choking, ramming, and water hammering. These systems are now commonplace in new dredges and have been retrofit on many older dredges. Increased productivity from this system reduces the time per job by increasing cubic yards dredged per hour. Systems can be especially helpful when used in conjunction with long pipelines. Energy consumption per hour can increase slightly (approximately 3 percent), but overall energy per job (or per cubic yard) is reduced substantially.

Energy Savings Analysis

Productivity increases of 25 percent and more have been reported in the literature, with corresponding energy efficiency gains of 17 percent (see references). Gains may vary somewhat, depending on pumping conditions and material density. For example, such systems will be most useful when dredging in silt and sand, although in very deep silt, production may decrease.

Energy Savings Rating B

Major Barriers or Issues

Suction relief systems appear to have relatively wide retrofit potential. However, this must be evaluated on a case-by-case basis, depending on existing plant specifications, anticipated job requirements, and engineering-economic analyses of costs and benefits. The use of swell compensators and improved winches on new Corps dredges has reduced the need for suction relief systems. Also air injection systems with suction relief valves may not be advisable.

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ENERGY STRATEGY 6

Major Area Pumps and Pipelines

Strategy Title Production Meters

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham	X	Ste. Gene.	X
McFarland	X	Thompson	X
Yaquina			

Description

Flow meters traditionally have been used to measure the amount of dredged material for payment or measurement of dredge capacity. However, accurate metering of production flow rates and specific gravity can also help optimize production by monitoring the effects of controlled changes in factors such as swing speed, depth of cut, and speed. Continual monitoring of flow rates can then be used as a basis for identifying needed adjustments in operating parameters.

Energy Savings Analysis

Energy savings from this option will be ship- and job-specific. Since this strategy applies only to the older dredges, and since operating experience with these dredges is extensive, it is hypothesized that efficiency improvements would be limited to the 0 to 3 percent range.

Energy Savings Rating A

Major Barriers or Issues

Adoption of improved monitoring systems involves both the physical installation of equipment and the training of personnel in its effective use. If not used on an ongoing basis, improved monitoring of flow rates will not improve productivity. Fully automatic systems, though more expensive and technically complex, would eliminate this potential problem. Evaluation of potential improvements from such systems and their applicability to older dredges will need to be conducted on a case-by-case basis. Automatic systems, if applicable, can also decrease manpower requirements.

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ENERGY STRATEGY 7

Major Area Dredge Arm and Head

Strategy Title Hull Digging Head Positioning Equipment

Applicability

Wheeler		Jadwin	
Essayons		Potter	X
Markham		Ste. Gene.	X
McFarland		Thompson	X
Yaquina			

Description

The past few years have seen major improvements in electronic equipment for positioning both dredge hulls and digging heads, and for producing more accurate and efficient before-and-after surveys. This equipment aids in rapid setup and locating at the dredge site and also reduces time lost to over-dredging.

Energy Savings Analysis

The major energy-related changes from these systems are through improvements in production rates associated with more rapid positioning and elimination of overdredging. Such improvements are ship- and job-specific. Overall efficiency improvements are thought to be in the 0 to 3 percent range.

Energy Savings Rating A

Major Barriers or Issues

There appear to be no major barriers to installing these systems. Durability of the electronic components in marine environments reportedly has been improving.

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ENERGY STRATEGY 8

Major Area Dredge Arm and Head

Strategy Title Head Design

Applicability

Wheeler	X	Jadwin	X
Essayons	X	Potter	X
Markham	X	Ste. Gene.	X
McFarland	X	Thompson	X
Yaquina	X		

Description

The different physical properties of granular and plastic materials are such that dredge efficiency can be improved by better matching material characteristics with draghead design. In addition, it may be possible to improve productivity further through research and development to upgrade head design.

Also requiring further exploration are active head techniques such as jet eductor systems that use high-pressure water injected through a venturi opening near the working surface of the suction pipe. In certain working conditions, the eductor can increase dredging productivity by adding energy on the suction side of the dredge pump; this permits faster pump speeds and higher solids content before cavitation. For dredges not equipped with submersible pumps, the eductor system also allows for dredging at greater depths than is possible without it.

Energy Savings Analysis

Although published data are limited, there are reports of production increases on the order of 11 to 45 percent (depending on the gas content of the dredged material). A poor match between material and head design can decrease productivity. Thus, energy savings, while greater than 15 percent under some conditions, are job- and ship-specific.

The literature provides only limited empirical documentation of productivity and energy efficiency improvements attributable to jet eductor systems. Unverified feedback from users suggests a typical increase in percentage solids from 10 to 15 percent. Computer simulation has suggested potential productivity gains as high as 85 percent; however, these are not documented empirically based on actual installed systems. Actual use has met with far more limited success.

Because of the limited evidence for actual energy savings associated with head design options, this strategy has been given a relatively conservative "B" rating for potential energy savings. It should be recognized, however, that depending on the attention currently given to head optimization or specific dredges, actual savings could vary substantially on a job- and ship-specific basis.

Energy Savings Rating B

Major Barriers or Issues

Head optimization requires research and development (R&D) to specify design and operational parameters. In practice, it involves additional costs for multihead system purchase, storage space, and increased downtime for head switching.

Jet eductors can be retrofitted to existing equipment, although ladder modifications may be required because of the added weight. The injector pump and its engine (if separate from the main dredge pump engine) must be located on or below deck. In many cases, higher energy gains would be possible with complete pump system redesign. Reports from dredge operators indicate that active heads are useful only for certain materials. Thus, applicability and variations in design must be determined on a case-by-case basis. Limited literature and practical experience with these systems makes additional R&D imperative before they could be considered seriously for Corps dredges.

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ENERGY STRATEGY 9

Major Area Propeller and Hull Modifications

Strategy Title Hull Coatings

Applicability

Wheeler	X	Jadwin	X
Essayons	X	Potter	X
Markham	X	Ste. Gene.	X
McFarland	X	Thompson	X
Yaquina	X		

Description

Immediately after a dredge enters the water, some fouling of the hull surface occurs. This progressively increases the hull's surface roughness and corresondingly increases fuel consumption. Even with periodic cleaning, the base roughness continues to increase and the ability of conventional anti-fouling paints to resmooth the surface decreases. So-called "self-polishing" coatings (acrylic-based organotin copolymers) can improve the in-service performance through progressive smoothing of the hull surface. As the time in service between drydockings increases, the average hull roughness decreases along with frictional resistance.

Energy Savings Analysis

Since frictional resistance is the major component of moving resistance in ship operation, self-polishing hull coatings can reduce the power requirements for propulsion. The fuel savings attributable to these coatings can range from 2 to 8 percent if applied over the entire hull. Coating the first one-quarter of ship length can result in savings of 0 to 3 percent.

Energy Savings Rating A

Major Barriers or Issues

The actual savings attributable to this strategy will depend on several factors:

- Time in service between drydocking
- Adequacy of surface preparation
- Temperature and chemical and biotic content of operational waters.

Potential problems also must be assessed with respect to air quality during coating application.

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ENERGY STRATEGY 10

Major Area Hull and Propeller Modifications

Strategy Title Efficient Use and Maintenance of Propellers

Applicability

Wheeler		Jadwin	X
Essayons		Potter	X
Markham	X	Ste. Gene.	
McFarland	X	Thompson	X
Yaquina			

Description

In many cases, fuel savings may be possible through better matching of the propeller with plant and mission (for ships with controllable pitch [CP] propellers, this amounts to having the right trim set). Ships that frequently run at lower-than-design speed generally are saving fuel, but a different propeller with a slightly larger diameter will yield higher mechanical efficiency and even greater energy savings. The Corps has traditionally done a good job of propeller matching during the design phase. However, for the older dredges, advanced propeller design and mission changes would suggest the merit of a propeller design review. From an energy standpoint, it would also be important that CP propellers continue to operate in an optimal mode.

Energy Savings Analysis

On ships equipped with a CP propeller, the correct trim must be set to prevent a fuel penalty. The CP propeller can also compensate for the progressive increase in hull resistance due to fouling. Fuel savings in the range of 3 to 10 percent are possible, depending on the match of propeller pitch with ship conditions. For non-CP-equipped ships, installing a new propeller that is better matched to ship operating speeds and loads may enable efficiency gains of .5 to 1 percent, along with any gains attributable to speed lowering.

Energy Savings Rating A

Major Barriers or Issues

Because of the difficult environments experienced in dredge operation, a major implication of increased attention to propellers is that the noneffective time required for maintenance operations would increase. However, it is possible that with appropriate planning, these operations could be conducted at the same time as other maintenance activities.

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